

SUSTAINABLE RETROFITS FOR RESIDENTIAL BUILDINGS BASED ON LEED v4.1 OPERATIONS AND MAINTENANCE



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by

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**SUSTAINABLE RETROFITS
FOR RESIDENTIAL BUILDINGS BASED ON LEED v4.1
OPERATIONS AND MAINTENANCE**

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To my beloved family...

ABSTRACT

The buildings and construction industry are responsible for almost 40% of energy- and process-related emissions. For this reason, the Paris Agreement announced that a 30% improvement in energy usage per sqm of buildings is needed until 2030 to reduce the high carbon emissions produced by buildings and the construction industry. Hence, the tendency in the architecture, engineering, and construction (AEC) industry is to reduce the resource consumption of buildings. At this point, there is a vital need to retrofit the existing buildings sustainably to fulfill the global climate targets described in the Paris Agreement. The research objective of this study is to (1) retrofit a five-story residential building based on the LEED v4.1 Operations and Maintenance (O+M) and (2) compare the resource consumption and carbon emission release of sustainable retrofitted buildings and conventional existing buildings. Based on the LEED v4.1 O+M, nine alternative scenarios are used in the study to reduce the building's current energy consumption and CO₂ emissions. In this scope, energy, water, and lighting performance, as well as the carbon emission production rate of the building, are calculated via DesignBuilder for each scenario. The results reveal that each retrofitting method has a varied effect on lowering energy consumption and CO₂ emissions in existing buildings. The combined scenario reduces the annual CO₂ emission in the existing building from 34437.89 kg to 16668.9 kg, representing a 51% decrease in CO₂ emissions. The findings of this study show that combining numerous retrofit methods can save up to 50% of energy in Tabriz-climate residential buildings. The results of this research will contribute to the AEC industry and literature by indicating the design process and value of sustainable retrofits for residential buildings based on LEED v4.1 Operations and Maintenance. Practitioners in sustainable

construction projects and researchers focusing on green buildings could benefit from the results of this research.



ÖZETÇE

Binalar ve inşaat endüstrisi, enerji ve süreçle ilgili emisyonların yaklaşık 40%'ından sorumludur. Bu nedenle, Paris Anlaşması, binaların ve inşaat endüstrisinin ürettiği yüksek karbon emisyonlarını azaltmak için 2030'a kadar metrekare başına bina başına enerji kullanımında 30'luk bir iyileştirmenin gerektiğini açıklamıştır. Bu nedenle, mimarlık, mühendislik ve inşaat (MMİ) endüstrisinde eğilim, binaların kaynak tüketimini azaltmaktır. Bu noktada, Paris Anlaşması'nda tanımlanan küresel iklim hedeflerini karşılamak için mevcut binaları sürdürülebilir bir şekilde yeniden düzenleme konusunda hayati bir ihtiyaç bulunmaktadır. Bu çalışmanın araştırma hedefi, (1) LEED v4.1 İşletme ve Bakım (O+M) kriterlerine dayalı olarak beş katlı bir konut binasını iyileştirmek ve (2) sürdürülebilir bir şekilde iyileştirilmiş bina ile geleneksel mevcut binanın kaynak tüketimini ve karbon emisyon salımını karşılaştırmaktır. LEED v4.1 O+M temel alınarak çalışmada dokuz farklı senaryo kullanılarak binanın mevcut enerji tüketimini ve CO₂ emisyonlarını azaltmak için çeşitli yöntemler incelenmiştir. Bu kapsamda, her senaryo için bina enerji, su ve aydınlatma performansı ile karbon emisyon üretim oranı DesignBuilder aracılığıyla hesaplanmıştır. Sonuçlar, her dönüştürme yönteminin mevcut binalardaki enerji tüketimini ve CO₂ emisyonlarını azaltmada farklı bir etkisi olduğunu göstermektedir. Kombine senaryo, mevcut binanın yıllık CO₂ emisyonunu 34437.89 kg'dan 16668.9 kg'a düşürerek CO₂ emisyonlarında 51%'lik bir azalmayı temsil etmektedir. Bu çalışmanın bulguları, Tabriz iklimindeki konut binalarında çeşitli dönüştürme yöntemlerini birleştirmenin enerji tasarrufu sağlayabileceğini göstermektedir. Bu araştırmanın sonuçları, LEED v4.1 Operasyon ve Bakım temel alınarak konut binaları için sürdürülebilir dönüşümlerin

tasarım sürecini ve deęerini gstererek MMİ endüstrisine ve literatürüne katkıda bulunacaktır. Sürdürülebilir inşaat projelerine odaklanan uygulayıcılar ve yeşil binalara odaklanan araştırmacılar, bu araştırmanın sonuçlarından faydalanabilirler.



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TABLE OF CONTENTS

DEDICATION	iii
ABSTRACT	iv
ÖZETÇE	vi
ACKNOWLEDGEMENTS	viii
LIST OF TABLES	xii
LIST OF FIGURES	xiii
I INTRODUCTION	1
1.1 Research Gap	2
1.2 Research Objective	3
II RESEARCH BACKGROUND	4
III RESEARCH METHODOLOGY	12
3.1 Systematic literature review	13
3.2 Case Study	14
3.2.1 Determination of the case study building's characteristics	14
3.2.2 The climatic condition of the case study location	17
3.2.3 Determination of the Case Study Buildings' Energy Performance	19
3.2.4 Calibration of case study	19
IV CASE STUDY ANALYSIS	21
4.1 Application of LEED (Leadership in Energy and Environmental Design)	21
4.2 Location and Transportation	23
4.3 Sustainable sites	26
4.3.1 Sustainable Sites: Rainwater management	26
4.3.2 Sustainable Sites: Heat Island Reduction	26
4.3.3 Sustainable Sites: Light pollution reduction	27
4.3.4 Sustainable Sites: Site Management	27

4.4	Water efficiency	27
4.5	Energy and atmosphere	28
4.5.1	Energy and Atmosphere: Energy performance	28
4.5.2	Energy and Atmosphere: Fundamental Refrigerant Management	29
4.5.3	Energy and Atmosphere: Enhanced Refrigerant Management	29
4.6	Material and Resources	30
4.6.1	Material and Resources: Purchasing policy	30
4.6.2	Material and Resources: Waste performance	31
4.7	Indoor environment quality	32
4.7.1	Indoor Environment Quality: Minimum Indoor Air Quality Performance	32
4.7.2	Indoor Environment Quality: Environmental Tobacco Smoke Control	33
4.7.3	Indoor Environment Quality: Green Cleaning Policy	33
4.7.4	Indoor Environment Quality: Indoor Environment Quality Performance	34
4.8	Innovation	42
4.9	Performing retrofit scenarios	42
V	RESULTS	44
5.1	The results of existing building' energy analyses in Tabriz	44
5.2	CO ₂ emission result of existing building and scenarios	46
5.3	Scenario 2: PV panels	47
5.4	Scenario 3: Replacing lighting fixtures.	52
5.5	Scenario 4: External wall Insulation	54
5.6	Scenario 5: Replacing windows	58
5.7	Scenario 6: HEAT ISLAND- Sustainable sites	60
5.8	Scenario 7: Waste performance	62
5.9	Scenario 8: Light pollution reduction	62
5.10	Scenario 9: Combined scenario	63

VI DISCUSSION	68
VII CONCLUSION	73
REFERENCES	76
VITA	81



LIST OF TABLES

1	Tabriz residential building geometry	15
2	Tabriz's geographical location	18
3	Monthly calibration of electricity consumption of existing building and simulation results	20
4	LEED v4.1 existing buildings O+M scorecard.	22
5	The appliance's refrigerant in the case study	30
6	Purchasing policy of Tabriz building	31
7	Natural ventilation for residential units. Source: LEED O+M guidance	33
8	TVOC level on the 10th of February 2023.	40
9	CO ₂ amount on the 10th of February 2023.	40
10	TVOC level on the 22nd of September 2023.	41
11	CO ₂ amount on the 22nd of September 2023.	41
12	PV panel feature	49
13	The difference between wall layers before and after applying scenario 4.	56
14	Window type for Scenario 5	58
15	Reflective roofing material.Source: CIBSE Guide A, Table 3.36	60
16	Summary of results for all scenarios	64
17	Scenarios with technical information of materials used.	65
18	Summary of LEED Credits earned in case study.	66

LIST OF FIGURES

1	Electricity consumption by sector, Islamic Republic of Iran 1990-2020.	4
2	CO ₂ emissions per GDP in all nations in 2021.	5
3	Total CO ₂ emissions in Iran from 1990 to 2021.	6
4	IDEF0 diagram illustrating the process of methodology.	12
5	Drawing case study building in DesignBuilder software.	16
6	Case study building	16
7	Plan of case study in Tabriz	17
8	Schedule of building occupant activity. (Left): Living room (Right): Bedroom	17
9	Tabriz location	18
10	Cumulative survey responses for LT Source: Author-based on Arcskoru website	24
11	Popularity of transport modes of the case study. Source: Author-based on Arcskoru website	24
12	Location of case study	25
13	Distance from case study to subway and bus station	26
14	The total amount of water consumed by each occupant. Source: Author- based on Arcskoru website	28
15	Energy consumption of the building in the last 12 months based on the bills. Source: Author-based on Arcskoru website	29
16	Waste generated. Source: Author-based on Arcskoru website	31
17	Occupant satisfaction survey. Source: Author-based on Arcskoru website	34
18	Satisfaction rating and feedback of residents' responses. Source: Author- based on Arcskoru website	37
19	CO ₂ emission on the 10th of February and on the 22nd of September. Source: Author-based on Arcskoru website	37
20	TVOC level on the 10th of February and on the 22nd of September. Source: Author-based on Arcskoru website	38

21	TVOC and CO ₂ measurements in February and September. (a): 10th of February 4th, 2023, floor kitchen (Left), 22nd of September 2023 4th floor kitchen (Left). (b): 10th of February 4th, 2023, floor Livingroom (Left), 22nd of September 2023 4th floor Livingroom (Left). (c): 10th of February 4th, 2023, floor Master bedroom (Left), 22nd of September 2023 4th floor Master bedroom. (d): 10th of February 4th, 2023, floor bedroom (Left), 22nd of September 2023 4th floor bedroom.	39
22	Annual EUC of the case study building before retrofitting in scenario 1	45
23	CO ₂ Emission per year in different scenarios	46
24	Iran's photovoltaic power potential.	48
25	Annual EUC of the case study building for scenario 2.	50
26	Total fuel consumption of scenario 2.	51
27	Annual EUC of the case study building for scenario 3.	53
28	Thermal bridge of the (a) Living room, (b) master bedroom, and the (c) bedroom from inside the building in two distinct seasons.	55
29	Annual EUC of the case study building for scenario 4.	57
30	Annual EUC of the case study building for scenario 5.	59
31	Annual EUC of the case study building for scenario 6.	61
32	Heat loss of wall and glazing before and after retrofitting.	63
33	Annual EUC of the case study building for scenario 9	71
34	The entire project's certification eligibility, source: Author based on LEED v4.1 Existing Building O+M guidance.	72

CHAPTER I

INTRODUCTION

One of the world's biggest challenges is the large amount of energy consumed and carbon released by the building and construction industries [1]. Buildings in developed countries have been estimated to consume nearly 40% of global energy [2, 3] and contribute to around one-third of greenhouse gas emissions [4]. Energy consumption is a significant challenge that affects the natural environment [5], causes the release of pollutants such as carbon emissions [6], and contributes to climate change [7]. Global energy consumption has grown in the last decade due to global warming and the limitation of non-renewable energy sources [8, 9].

Many politicians, professionals, and other stakeholders recommend energy retrofits that decrease buildings' dependence on fossil fuels or the GHG emissions associated with renewable systems or consider various retrofit solutions to reduce energy consumption and mitigate buildings' consequential impact on the climate by Greenhouse Gases (GHGs)[10]. Retrofit solutions aim to reduce GHG emissions by lowering buildings' operating energy consumption and carbon footprint [11]. Retrofits often include an initial investment in enhancing existing building systems (such as envelope thermal efficiency and smart building technologies) or installing new renewable energy systems (such as photovoltaics/solar heat collectors) [12, 13]. The retrofit solutions will decrease energy use and greenhouse gas emissions, reducing energy consumption [6, 14]. Energy use in residential buildings must be regulated to meet the Paris Agreement's climate targets and comparable aims [15]

Therefore, all countries have focused on enhancing energy efficiency to solve this vital issue. The U.S. Energy Information Administration (EIA) claims that, global

electricity use in residential buildings will grow twice as fast as natural gas use by 2050 in all cases, indicating a trend toward electrification, and global overall energy consumption will increase by roughly 50% between 2018 and 2050. A significant portion of this increase could be attributed to countries outside the Organization for Economic Cooperation and Development (OECD), including Iran [16].

Retrofitting residential buildings is essential nowadays because it makes existing buildings compliant with changing environmental standards while reducing carbon emissions and energy use. To ensure a systematic and effective strategy for improving energy performance, decreasing energy consumption, and mitigating environmental impact, improving existing buildings with an energy certification system such as Energy and Environmental Design (LEED) [17] is essential.

1.1 Research Gap

Limited studies are conducted on retrofitting residential buildings, mainly assessing the costs associated with retrofitting [18]. Surprisingly, only some studies are associated with LEED v4.1 without eliminating or filtering in the Scopus and Web of Science databases. The fact that there are not a few publications on these topics shows that considerable study remains essential.

A thorough search of authoritative academic databases, particularly Scopus and Web of Science, indicated a significant need for existing literature reviews dedicated to LEED v4.1. Despite the fundamental importance of this advanced version in guiding existing sustainable residential building practices, scholarly discussion on these subjects needs to be more present in studies. Less than two documents for LEED v4.1 existing residential building operation and maintenance in the Scopus and Web of Science databases show that scholarly discussion of LEED v4.1 O+M is still relatively new. This gap highlights unrecognized opportunities for unique and fundamental research in the residential building sector, representing a remarkable opportunity for

researchers and practitioners to initiate research that explains the complexities and implications of LEED v4.1 O+M.

1.2 Research Objective

In today's world, retrofitting existing buildings has become essential because it reduces energy consumption and carbon emissions, supports environmental sustainability, and is more cost-effective than building a new construction [19]. It also enables existing buildings to comply with LEED and other sustainability standards that are constantly evolving. This strategy helps preserve the environment and practice economic accountability by minimizing resource consumption, lowering carbon footprint, and optimizing the effective use of existing buildings.

To reduce the high level of carbon emissions produced by buildings and the construction sector, the Paris Agreement also stated that until 2030, a 30% improvement in energy consumption per square meter of buildings is required [20]. Existing buildings should be retrofitted sustainably to meet the Paris Agreement's global climate objectives. Relating to this issue, the research objective of this study is to:

(1) retrofit the five-story residential building based on the LEED v4.1 Operations and Maintenance (O+M), and (2) compare the resource consumption and carbon emission release of sustainable retrofitted building and conventional existing building. In this scope, energy, water, and lighting performance, as well as the carbon emission production rate of the building, are calculated via DesignBuilder.

CHAPTER II

RESEARCH BACKGROUND

The building sector in Iran consumes twice as much energy as the global average [21, 22]. Figure 1 illustrates Iran's energy consumption has increased in all sectors since 1990. Residential energy consumption increased by 3.7% annually from 2010 to 2020 [23].

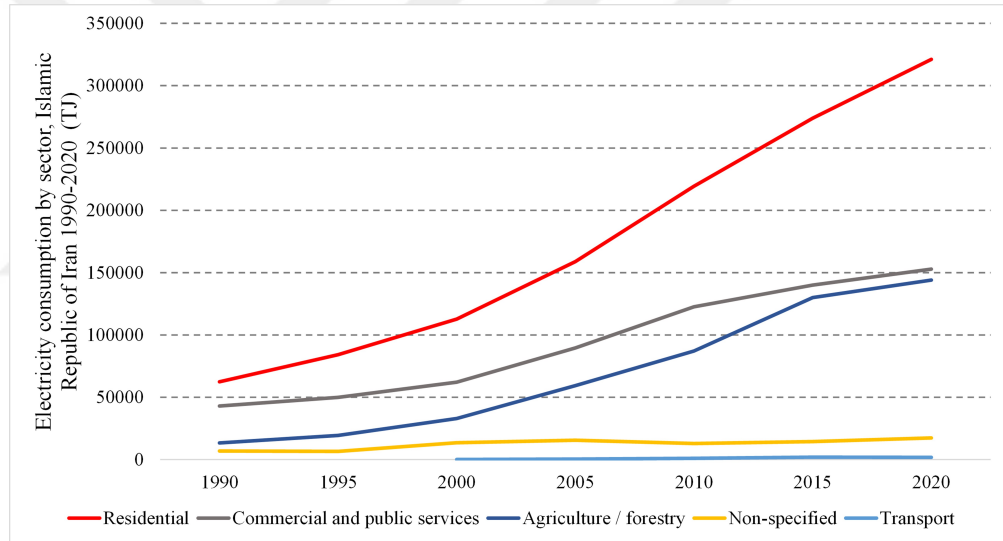


Figure 1: Electricity consumption by sector, Islamic Republic of Iran 1990-2020.

[23]

Figure 2 shows that among the 16 major CO₂ emitters responsible for more than 1% of global CO₂ emissions, seven countries, including Iran, have higher CO₂ emissions in 2021 than in 2019. In 2021, Iran has 0.55 CO₂ emissions per GDP (Gross Domestic Product) [24]. This increase in CO₂ emissions from significant contributors highlights the need for specific initiatives to mitigate the environmental effects of urban life in the context of residential buildings. Focusing on sustainable retrofits,

energy-efficient technology, and broad adoption of renewable energy sources within residential buildings has become critical to reducing the increasing carbon footprint of housing and contributing to global climate mitigation efforts. Figure 3 shows that in the analysis of the International Energy Agency, Iran’s CO₂ emissions have increased annually from 1990 to 2021, with the residential sector making a significant contribution [25].

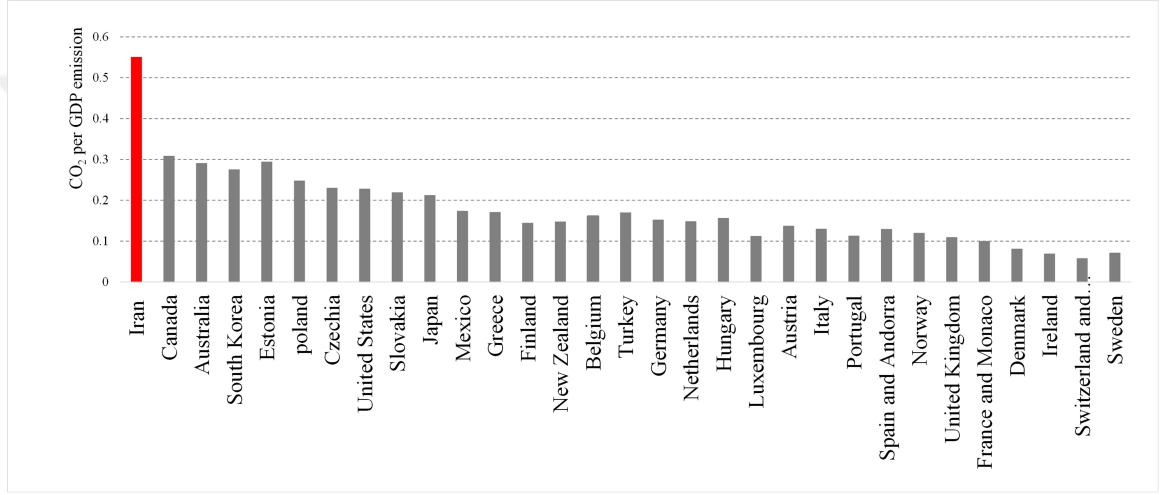


Figure 2: CO₂ emissions per GDP in all nations in 2021.

[24]

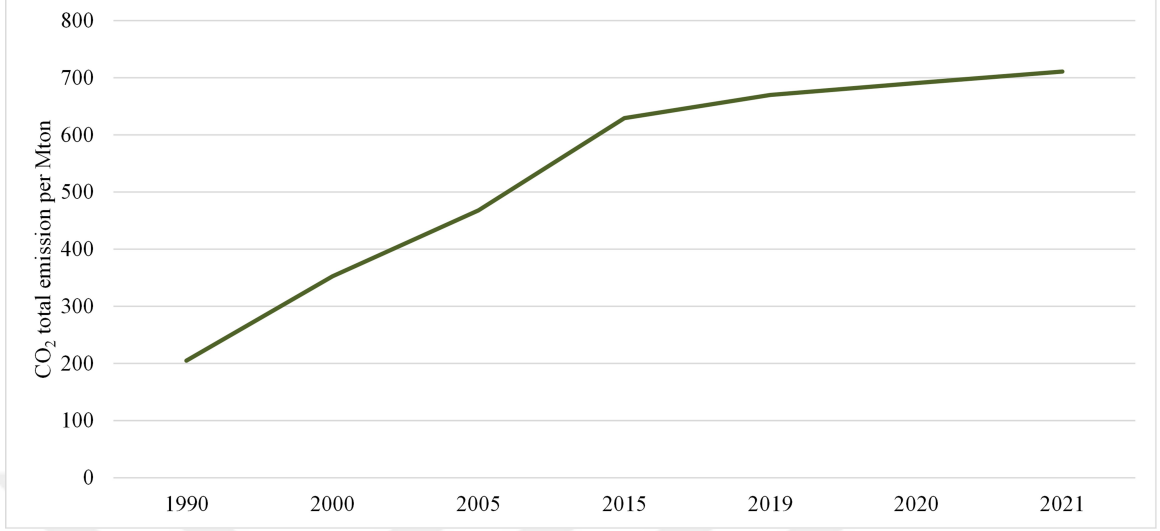


Figure 3: Total CO₂ emissions in Iran from 1990 to 2021.

[23]

Suppose the building sector in Iran tends to reduce global warming, which is increased by CO₂ emissions from buildings. In that case, sustainable retrofit energy scenarios should be adopted in all building sectors, especially in residential buildings, because residential buildings operate 24 hours a day, seven days a week. Since at least 65% of existing residential buildings will still operate by 2050, upgrading existing buildings to reduce energy usage is crucial [19].

Conventional residential buildings in Iran have always experienced energy consumption challenges, typically depending on traditional construction methods and materials that may not emphasize energy efficiency [26]. The diverse climatic conditions in various parts of Iran have an additional influence on the energy consumption of residential buildings [27]. Conventional building designs, construction processes, and materials used in typical residential buildings may lead to greater energy consumption, specifically in terms of heating and cooling demands, which can be significant given Iran's variable climate [28]. Tabriz is the capital of the province of East Azerbaijan in northern Iran [29]. Its cold climate causes buildings to lose heat rapidly,

causing cold air to flow through walls and roofs in winter. Many Tabriz buildings are built of concrete, which may result in heat loss and increased energy utilization [30].

Retrofitting projects in Iran confront additional obstacles due to the country's unique characteristics, such as subsidized energy costs and water and electricity prices [31]. Furthermore, because energy is cheap in Iran, fundamental energy consumption measurements in residential buildings have yet to be studied, and the factors influencing energy consumption have yet to be identified [32]. As a result, there is an urgent need for more studies on enhancing building energy efficiency, as many existing buildings in Iran do not meet energy efficiency standards [18, 30].

Despite having plenty of sustainable energy resources, Iran suffers from energy poverty because of insufficient energy-saving and consumption regulations, particularly in residential regions [31]. Iran had increases in its final energy consumption and carbon intensity of 67% and 81%, respectively, between 2001 and 2011. In other words, Iranian CO₂ emissions increased by 81 percent from 302 MT in 2001 to 547 MT in 2011. Total energy consumption in Iran increased from 637.8 million barrels of crude oil in 2001 to 1068.4 million barrels in 2011 [23]. The residential sector is the most significant factor influencing overall energy consumption in Iran. Iran's overall energy consumption can be decreased by focusing on the residential sector, aiming for a transition to renewable energy sources, and improving technology for production [33].

Mirzaei et al. (2020) performed a study to propose a simulation-based multi-objective optimization technique that improves the environment of buildings at the same time, and they identified combinations of retrofitting techniques to apply to residential buildings. The results of this case study demonstrate an improvement in the established goal functions [34]. Tavakolan et al. (2021) developed a multi-objective optimization framework based on simulation to improve building energy efficiency and

optimize the economic benefits of retrofitting. The findings show that, while significant reductions in primary energy consumption are possible, executing energy retrofit under Iran's existing energy pricing framework will not produce economic advantages. However, eliminating subsidies and providing incentives for building energy retrofits offers a favorable conclusion [31]. Balali et al. (2020) examined experts to detect and prioritize energy-saving methods in existing and ancient Iranian buildings. The relevance of this study is that energy consumption in Iran is increasing each year, and there is no solution to this problem [26]. Tahsildoost et al. (2015) conducted an experimental study that prioritized possibilities based on energy modeling and modified two typical Iranian school buildings. This study is critical because it is difficult to determine the best practice and preferable retrofit solutions by considering the findings of numerous feasibility studies on the energy-friendly, environmentally friendly, and efficient activities for the energy retrofitting of school buildings [18]. Motalebi et al. (2021) examined a study to enhance energy efficiency in buildings; the study presents a novel framework for energy retrofits that integrates mathematical optimization, 6D-building Information Modeling (BIM), and Life Cycle Assessment. Even though well-established buildings are regulated by minimal regulation, fundamental rules attempt to decrease environmental impact. Buildings in developing nations have a limited lifespan, which demands energy retrofit plans as their efficiency diminishes as they approach their service life. Retrofitting in this study could lower consumption by 24%-58%, reducing global warming impacts by more than 45%. This highlights the significance of building energy efficiency [35]. Tahsildoost et al. (2020) researched the best retrofit solutions for rural buildings in Iran, including Tabriz, based on economic viability, environmental effect, and positive comfort aspects. It offers a multi-criteria decision-making tool for retrofit projects to close the rural energy efficiency gap by rewarding energy efficiency measures and removing obstacles. In varied temperature zones, the results demonstrate primary energy demand reductions of 46-55%, carbon

emission reductions of 40-51%, and enhanced thermal comfort levels of up to 23% [7]. Movaheda et al. (2020) investigate the influence of green roof retrofitting solutions on energy consumption and CO₂ emissions in residential buildings across different temperature zones in Iran, including Tabriz. Green roofs could reduce energy consumption by 6.19%, 2.07%, and 9.45% in Tehran, Tabriz, and Bandar Abbas, respectively, and CO₂ emissions by 238 kg, 100 kg, and 370 kg per year, according to the findings [36]. Aghamolaei et al. (2020) examined an approach for optimizing building retrofit solutions in residential buildings to balance energy efficiency and thermal comfort. They determined the most critical retrofit activities using parametric sensitivity analysis (PSA) and genetic algorithms to minimize greenhouse gas emissions and thermal discomfort hours. The approach decreased the number of variables and computations required, demonstrating that artificial illumination, exterior wall insulation, airtightness, and the most successful retrofit options in lowering energy usage were artificial illumination [37].

The AEC sector has several worldwide and national green building rating systems (GBRSs). Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB), Energy Star, Green Star, and Comprehensive Assessment System for Built Environment Efficiency (CASBEE) are some prominent GBRSs. Despite their differences, the GBRSs perform identical operations, including assessing building environmental performance and the optimal use of natural resources such as energy, waste, and water. Among the Green Building Rating Systems (GBRR), the U.S. Green Building Council's (USGBC) LEED rating system is a worldwide recognized benchmark for analyzing and promoting environmentally sustainable and energy-efficient building practices. LEED, introduced in 1998, has played a vital role in transforming the construction and design sectors by offering a comprehensive framework for evaluating building environmental performance [17].

The method takes a step-by-step approach, considering energy and water efficiency, indoor air quality, and construction materials and resources. LEED v4.1 for Operations and Maintenance (O+M) allows existing buildings to pay special attention to building operations by enabling complete buildings and their interiors that have been fully operational and occupied for at least 12 months [38].

ElSorady et al. (2020) evaluated the passive construction features and environmental solutions of Bayt Al-Suhaymi, a historic Islamic residence in Cairo, using LEED v4.1. They measured interior environmental parameters such as total volatile organic compounds (TVOC) and CO₂ during winter and summertime. The residence was then evaluated using the LEED v4.1 rating system for existing buildings. One of the significant gaps in this study was that the LEED criteria and rating approach do not adequately analyze or score some of the essential sustainable aspects of historic structures, such as embodied energy in pre-existing buildings. Also, the process for implementing the LEED rating system in projects could be more precise, requiring a detailed review of its implementation methods and criteria. The key findings of this study are that this monument can achieve 79 points from the LEED v4.1 rating system and can potentially receive gold certification. [39]. Amiri et al. (2019) examined the economic and technical feasibility of seeking LEED certification for a residential building in Karaj, Iran. The building receives 29 points out of a potential 110 in the LEED rating system. Additional expenses of 3.4% and 5.9% of total building costs would be required to attain the LEED Certified and Silver standards. The location of a project and the available technology are essential factors in reaching the desired points. Previous research on the expenses of LEED certification has concentrated on older versions and developed nations [40]. Pushkar (2009) analyzed research on LEED-EB 2009 recertification projects and discovered that a four-point bonus scheme might reward lesser accomplishments in specific fields. The research examined 123 existing building projects in four different locations in the United States that received

both initial LEED certification and later recertification. According to the findings, the bonus system may have unforeseen consequences, including rewarding lesser success in particular areas [41]. Asdrubali et al. (2015) used two sustainable residential buildings in Italy to compare the LEED and ITACA building assessment approaches. Five common regions were discovered to compare the approaches and standardize their ratings. Both buildings performed well under both methodologies, with ITACA typically providing higher results due to its broader application in Italian. Although the approaches generally produced proportional outcomes for the buildings, they highlighted distinct characteristics [42].

However, these studies focus only partially on sustainable retrofit options for residential buildings in Tabriz based on LEED v4.1 O+M. Each city has a unique environment; thus, each should be carefully evaluated to discover the most applicable sustainable retrofit solution(s) to enhance the energy performance of existing buildings in that location. Therefore, this study aims to retrofit the five-story residential building based on the LEED v4.1 Operations and Maintenance (O+M) and compare sustainable retrofitted and conventional existing buildings' resource consumption and carbon emission release. In this scope, energy, water, and lighting performance, as well as the carbon emission production rate of the building, are calculated via DesignBuilder.

CHAPTER III

RESEARCH METHODOLOGY

This research methodology of the study consists of two key steps, a systematic literature review and the case study, to provide applicable solutions for energy-efficient retrofitting of existing residential buildings in Tabriz, Iran. An IDEF0 diagram shows the steps of the research methodology in Figure 4.

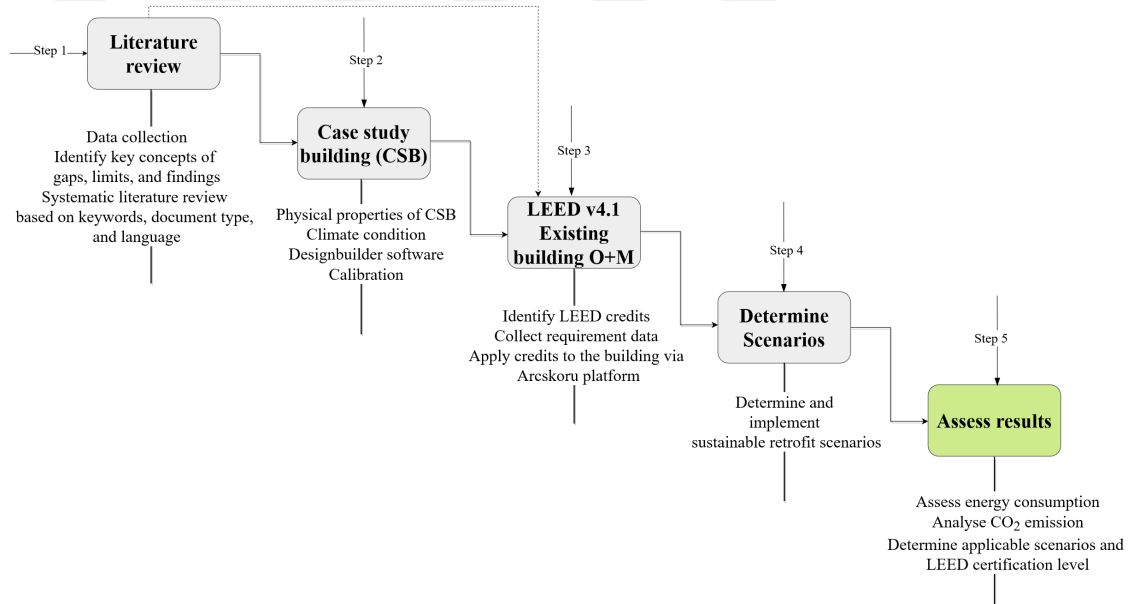


Figure 4: IDEF0 diagram illustrating the process of methodology.

3.1 Systematic literature review

A thorough literature review plays a role in research due to its rigorous methodology and ability to comprehensively combine existing knowledge[43]. A comprehensive literature assessment was conducted to investigate previous studies, identify gaps and lack of attention, and collect data on this subject. Systematic literature reviews can distinctly define the limits of scientific advancement in conjunction with contemporary industrial procedures within the study domain. The databases Scopus and Web of Science were chosen for this study because they are highly enriched platforms with easy access to find desired literature precisely. On the other hand, Scopus encompassed all discoveries collected from the Web of Science; hence, it was chosen to find literature. Documents obtained from Web of Science and Scopus were investigated, with title, keyword, and abstract assessments conducted. Keywords, document type, and language were chosen as criteria.

Five major topics LEED v4.1, LEED O+M, retrofit, residential building, and sustainable buildings were focus of the literature review. The manual exclusion criterion for the review includes looking thorough the titles, abstracts, and keywords of each document as well as reading the entire text to exclude any that do not discuss the advantages and/or difficulties of LEED v4.1, LEED O+M, or retrofit the residential building. Four documents that addressed the advantages and/or challenges of using LEED v4.1 were found during the review without eliminating and filtering, and only one of them focused on dwelling.

Without filtering, 75 papers were found using keywords from the residential building, retrofit, and energy simulation. filtering was used, in the period interval (2000-2024), sources, topic field, languages, country, and keywords. When 54 records were eliminated after considering their titles, abstracts, and keywords, along with reading their full texts, 21 relevant papers were determined. When documents addressing the benefits and/or problems associated with retrofitting residential buildings were

manually investigated among 21 records, only eight articles were defined.

Since these topics are relatively new and many articles such as articles, conference proceedings, theses, and book chapters are unavailable, filtering is not used when reviewing the existing LEEDv4.1 and LEED O+M building literature. Twelve articles on the benefits and problems of retrofitting residential buildings in addition to LEED version 4.1 operations and maintenance were found. Citavi was selected to manage and store the documents. A comprehensive analysis of the text was then carried out.

3.2 Case Study

3.2.1 Determination of the case study building's characteristics

Comprehensive information on the geometry, direction, number of floors, temperature zones, heating, ventilation, lighting systems, occupancy number, ratio, and building working schedules should be gained to model the case study building. AutoCAD and DesignBuilder were used for this purpose. While modeling the case study building, thermophysical properties like U-value, Solar Heat Gain Coefficient (SHGC), wall, roof, and floor thickness, infiltration rate, the thermal mass of building elements, shading devices, window frame material, and characteristics, and properties of shading elements should be considered. In addition, schedules, lighting system characteristics, set-point temperatures, natural and/or artificial ventilation, ventilation rates, humidity levels, set-points, equipment information, fuel, and renewable systems were identified for the building system.

The case study's building is a five-story building. Each floor contains a single residence unit with a 3.10-meter ceiling height, two bedrooms, and a total area of 96.50 sqm (Table 1). The building's north-south orientation is based on the Tabriz climate. Floor 5 differs from the previous floors, with a smaller area of 62 sqm and a single bedroom (Figures 5, 6, and 7).

An occupancy schedule is essential to the building simulation and energy analysis

process in DesignBuilder. It is a data entry that indicates which times of day certain building areas are occupied or empty. Through integrating occupancy schedules, users may replicate authentic fluctuations in building use across time, impacting the functioning of lights, HVAC systems, and other energy-intensive components. With the assistance of this feature, energy consumption patterns may be represented more accurately, allowing analysts and designers to evaluate and optimize building performance considering actual conditions. Therefore, an occupancy schedule leads to the creation of more sustainable and energy-efficient building designs. The occupant schedule provided in this study is shown in Figure 8.

Table 1: Tabriz residential building geometry

Building Geometry	Description	Value	Unit
Type of building	Residential	-	-
Status	Existing building	-	-
Orientation	North-south	0	Degree
Total Building Area	-	436.85	sqm
Net Conditioned Building Area		359.7	sqm
Each floor area	-	96.5	sqm
Number of floors	-	5	
Number of units on each floor	-	1	-
Floor height	-	3.1	m
Occupancy density	0.017 (Floor 1 to 4), 0.015 (Floor 5)	-	People/m ²
Total building Volume		1115.08	m ³
Gross Wall Area	North:102.56, East:117.15 South:117.15, West:102.88		sqm
Gross Roof Area		107.93	sqm
Window Opening Area	North:11.23, East:0.00 South:25.20, West:0.00		sqm
Program Version and Build	EnergyPlus, Version 9.4.0-998c4b761e		
Weather File	Tabriz - IRN ITMY WMO=407060		
Hours Simulated		8760	hrs

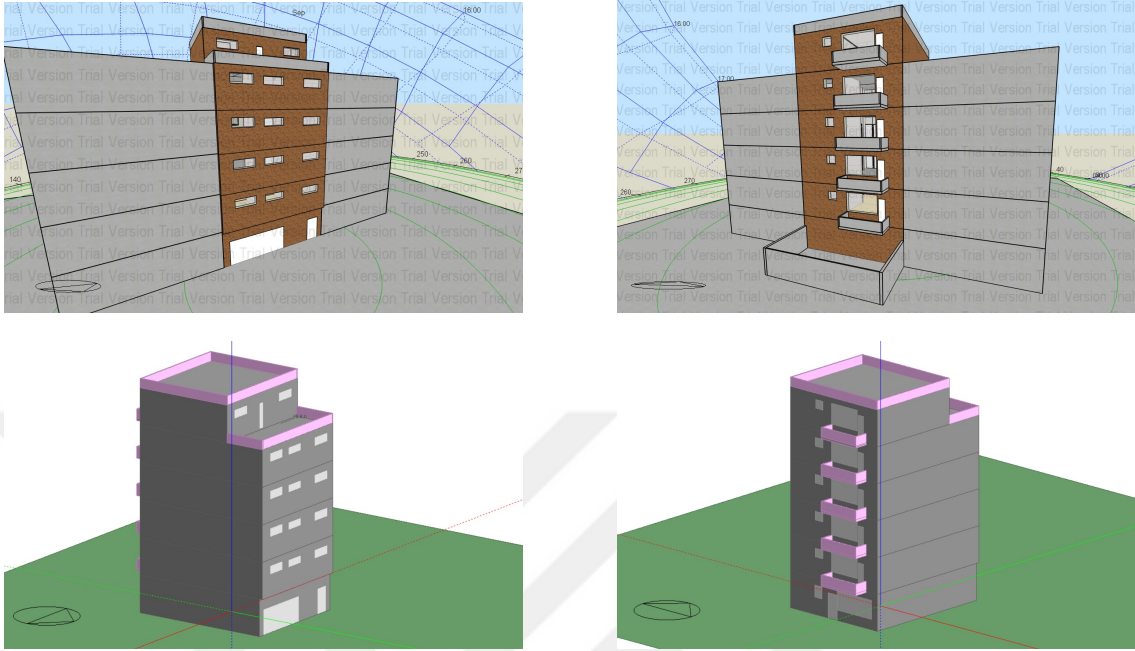


Figure 5: Drawing case study building in DesignBuilder software.



Figure 6: Case study building

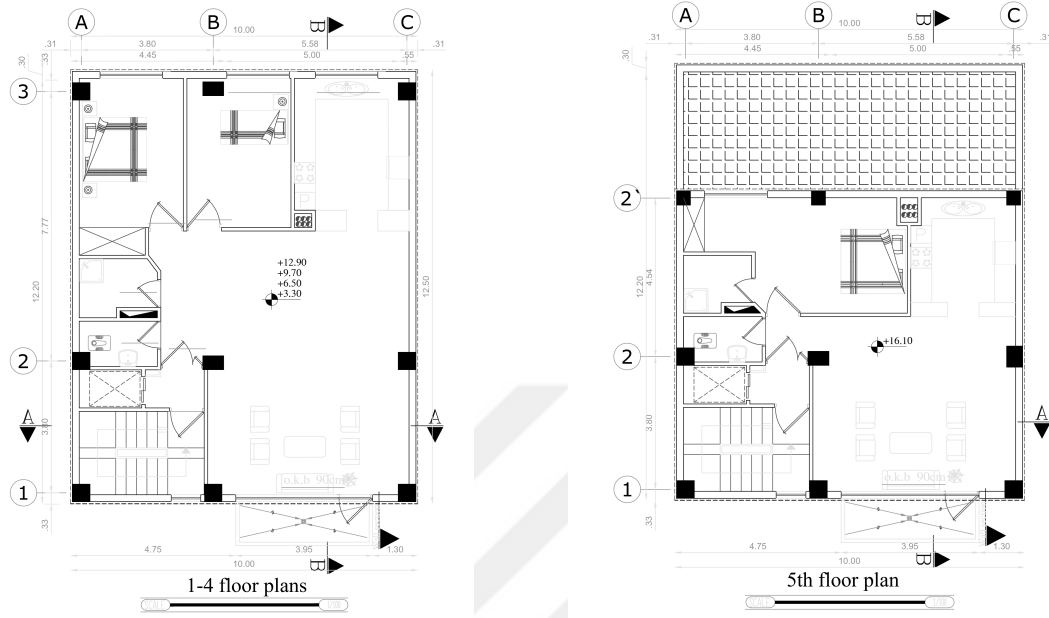


Figure 7: Plan of case study in Tabriz

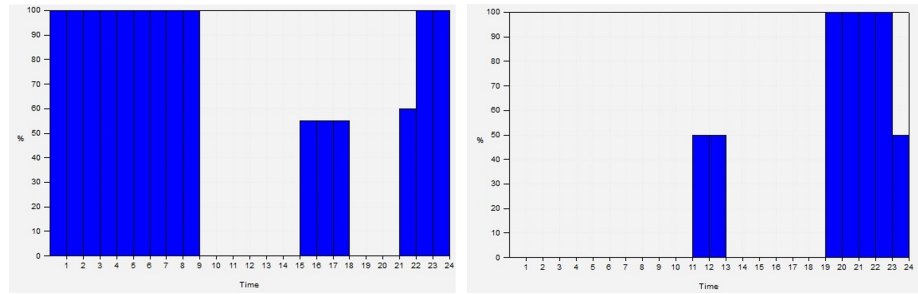


Figure 8: Schedule of building occupant activity. (Left): Living room (Right): Bedroom

3.2.2 The climatic condition of the case study location

The case building is in Tabriz, Iran. Tabriz is a city in northwest of Iran (Figure 9)[2]. The city is located 38.5° north of the equator and 46.16° east of Greenwich, England. Köppen and Geiger classify its climate as BSk [3], with severe winters and hot, dry summers. Tabriz is 1351 meters above sea level. Summer and winter

humidity levels are both low. Throughout the year, temperatures typically range from -5°C to 33°C , with temperatures seldom decreasing below 11°C or exceeding 37°C . Tabriz's geographical location is shown in Table 2. The climate parameters utilized in the analysis were obtained from the Energy Plus database. The yearly rainfall average is 323 mm. In a chilly environment, the average monthly temperature is 11.6°C . The temperature differential between the warmest and coldest months is 41 degrees Celsius, with at least four months below 3 degrees Celsius [44, 29].



Figure 9: Tabriz location
[29]

Table 2: Tabriz's geographical location

Latitude	38.07° N
Longitude	46.23° E
Climate	Cold and dry area
Elevation above sea level	1351

3.2.3 Determination of the Case Study Buildings' Energy Performance

The case study building was modeled in DesignBuilder to calculate its energy consumption, and the findings were compared with electricity consumption bills to calibrate the energy consumption. DesignBuilder is a powerful simulation software for Building Energy Modeling (BEM). This software uses Algorithms of EnergyPlus software to calculate building energy consumption according to climate, carbon emissions, occupancy, and system efficiency requirements. It also provides tools for examining daylighting, natural ventilation, and renewable energy integration. In addition, it is a user-friendly modeling software that allows researchers to work with virtual models of buildings. In addition, this comprehensive dynamic modeling software may calculate the energy performance of a building over different periods, with an annual period serving as the appropriate calculation period for this study. DesignBuilder provides environmental performance data such as annual energy consumption, peak summer temperatures, and HVAC component sizes.

3.2.4 Calibration of case study

Model validation assures the accuracy and quality of the simulation data provided. Personal communication with residents was conducted to obtain the energy bill consumption for one year and calibrate it with simulation results. Monthly electrical usage for one year of building based on bills and simulation results is given in Table 3.

Table 3: Monthly calibration of electricity consumption of existing building and simulation results

Monthly calibration	Reference	DesignBuilder results
	kWh	kWh
February	2673	2559
March	2810	2829
April	2680	2550
May	2688	2666
June	2536	2581
July	2803	2839
August	2606	2623
September	2741	2739
October	2898	2839
November	2787	2739
December	2875	2832

Hajizadeh and Seyis (2022) examined a five-story residential building in Tabriz. This study has annually normalized energy usage of 235.22 kWh/sqm [30]. In addition, Ebadati and Ehyaei (2020) reported an annual normalized energy consumption of 245.75 kWh/sqm for a residential building in Tabriz [45]. Furthermore, this thesis case study's normalized yearly energy consumption is 229.30 kWh/sqm, indicating solid overlap with previous studies. Furthermore, Equation 1 calculated an error ratio of 1.03 % for the case study building. Therefore, the results of the electricity energy and, as a result, the Tabriz baseline's annually normalized energy consumption are validated.

$$Error\% = \frac{Existingbuilding - simulated}{reference} * (100) \quad (1)$$

CHAPTER IV

CASE STUDY ANALYSIS

4.1 Application of LEED (Leadership in Energy and Environmental Design)

LEED (Leadership in Energy and Environmental Design) is used for developing retrofitting strategies for the existing residential building because LEED is the most widely used green building rating system in the world [38]. LEED assessment system includes several rating systems considering the building types and phases. These rating systems are LEED BD+C (Building Design and Construction), LEED ID+C (Interior Design and Construction), LEED O+M (Operations and Maintenance), LEED ND (Neighborhood implementation). Further programs for construction Performance and Sustainable Land Development offer LEED a comprehensive framework for environmentally responsible and sustainable construction practices [39]. LEED O+M has been chosen as the primary approach for this study as this rating system addresses the operations and maintenance of existing buildings. A total of 100 points can be collected in the rating system of LEED O+M. LEED certification rating levels in this category are classified as Certified (40-49 points), Silver (50-59 points), Gold (60-79 points), and Platinum (80+ points).

100 points are allocated to seven categories in LEED v4.1 O+M: Material and Resources (MR), Water Efficiency (WE), Sustainable Sites (SS), Location and Transportation (LT), Energy and Atmosphere (EA), Indoor Environment Quality (IEQ), and Innovation. There are a bunch of credits in each category, each with a maximum possible number of points stated (Table 4). Prerequisites are requirements for some of the categories; no points are awarded for meeting prerequisites. The following

credits were selected for the case study, and the number of credits in each category and the points allocated to each credit are displayed in Table 4. In the study, 58 can be achieved with the proposed retrofitting applications.

Table 4: LEED v4.1 existing buildings O+M scorecard.

<i>Categories</i>	<i>Prerequisites</i>	<i>Required points</i>	<i>Maximum Points possible</i>	<i>Points Earned in this project before retrofitting</i>
Location and Transportation	Yes	6	14	14
Sustainable sites	-	-	4	1
Water efficient	Yes	6	15	11
Energy and atmosphere	Yes	6.5	35	10
Material and resources	Yes	3	9	3
Indoor environment quality	Yes	8	22	19
Innovation	-	-	1	0
Total			100	58

To start the project, it is required to calculate the weighted occupancy, weighted operating hours, and gross floor area. Also, the following equation has been used to calculate weighted occupancy and weighted operating hours.

1. Weighted occupancy: The project's operating hours, also known as weighted operating hours, are the number of hours the building operates during an average whole week, equal to 168 (24/7) per week. Equation 2 is used for calculating space-weighted operating hours.

2. Weighted operating hours: The weighted occupancy of the project is the average number of users at any given time, which is equal to 10 people. Regular building people and visitors (3) are divided into two types. Equation 4 is used to calculate the total weighted occupants, which is space-weighted.

$$\begin{aligned}
Weightedoperatinghours &= \frac{(operatinghoursperweek * spacegrossfloorarea)}{totalgrossfloorarea} \\
&= \frac{(168 * (436.85 - 10))}{(436.85)} = 164hours/week
\end{aligned} \tag{2}$$

$$\begin{aligned}
Dailyaveragevisitors &= \frac{(\#visitorsperday)}{(operatinghoursperday) * durationofvisit} (2)/(24 * 2) \\
&= 0.041visitorsperhour
\end{aligned} \tag{3}$$

$$\begin{aligned}
Total\ weightedoccupants &= \sum (\#regularbuildingoccupants + \#averagedailyvisitors) \\
&10 + 0.041 \\
&= 10.041Totalweightedoccupants
\end{aligned} \tag{4}$$

Therefore, the total number of residents in the building is 10,041, but since this number is incorrect for counting people, the authors decided to consider 11 people for the entire building.

4.2 Location and Transportation

The Location and Transportation (LT) category of the LEED rating system emphasizes the building project's interaction with the surrounding community and the occupants' access to various ways of transportation. LT aims to decrease the impact of transportation on land development and pollutants. This category evaluates elements that support community connectedness and environmentally friendly ways of transportation.

The Location and transportation performance score can only be obtained using Arc to conduct the survey. According to the survey responses, most residents take

transportation or walk there since the case study is near work and the city's core. The minimal response rate is typically 25% of residents, equal to the minimum three responses in this study. The link to the survey was emailed to residents to complete the survey (Figures 10 and 11)

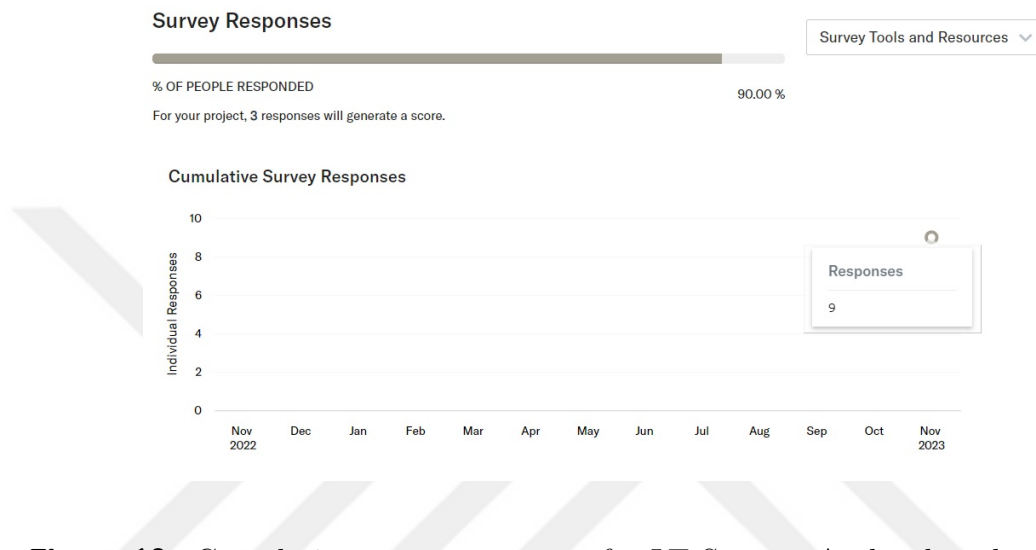


Figure 10: Cumulative survey responses for LT Source: Author-based on Arcskoru website

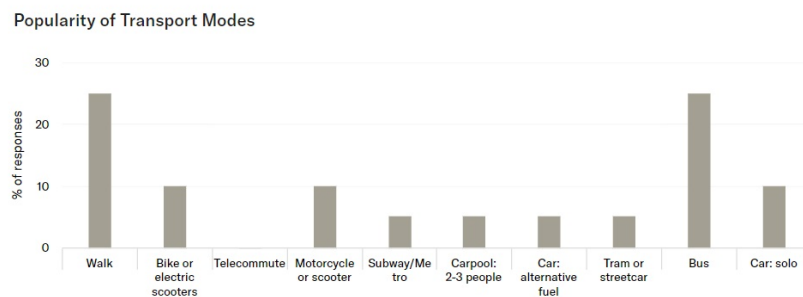


Figure 11: Popularity of transport modes of the case study. Source: Author-based on Arcskoru website

Figures 12 and 13 show the location of the case study and its distance from public transportation. As shown in Figure 13, the distance from the case study to the subway and bus station is 150m. The case study's accessibility to public transportation improves its environmental sustainability by reducing the need for private vehicle usage, contributing to reducing carbon dioxide emissions. The advantage of living near public transportation is that it encourages less reliance on personal automobiles, which aligns with sustainable aims.

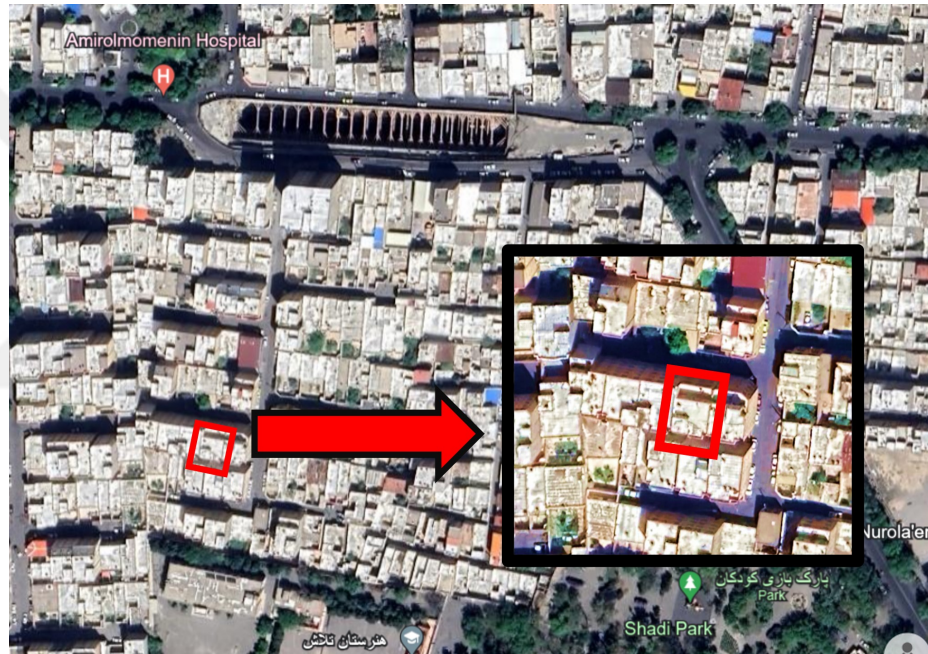


Figure 12: Location of case study



Figure 13: Distance from case study to subway and bus station

4.3 Sustainable sites

The LEED v4.1 Sustainable Sites (SS) category promotes environmentally conscious site selection and development techniques. It encourages reducing heat island impacts and managing rainwater to improve the project site's sustainability.

4.3.1 Sustainable Sites: Rainwater management

This credit must be computed for every project and is unavailable on the Arcskoru website. The case study could achieve 1 point in rainwater management because there is a vegetation area and a well in the yard; this well stores rainwater and can irrigate plants. Also, the heat island reduction could not achieve credit due to the lack of plants and light-colored roofs.

4.3.2 Sustainable Sites: Heat Island Reduction

The heat island effect occurs when vegetation is replaced by asphalt and building roofs in inhabited regions. These places have a higher temperature due to heat absorption,

such as by a building's roof. In reality, because the roof is black and constructed of absorbing material, it cannot reflect the heat. It is a priority for green buildings since the less heat the home absorbs, the less energy it requires to cool and the lower its carbon impact.

LEED v4.1 recommends a total of 1 point for implementing these solutions. Since the roof material does not comply with the credit and cannot be tracked by the surface's Solar Reflectance (SRI) value, this case study could not achieve 1 point from heat island reduction credit.

4.3.3 Sustainable Sites: Light pollution reduction

This credit aims to eliminate light pollution, which may obstruct views of the night sky and cause health issues for humans and ecological issues for many birds, insects, and other species. The light pollution reduction point was absent as there was no fixture Shielding of exterior lighting.

4.3.4 Sustainable Sites: Site Management

This credit intends to conduct site surveys to discover natural places that provide habitat. As in this project, there is no fertilizer or additives, soil testing would not be necessary, and there is no maintained turf area. As a result, this case study could not achieve one point from this credit.

4.4 *Water efficiency*

The Water efficiency (WE) category aims to assist with water management and minimize water use. This category requires permanently installed water meters that measure total potable water usage for the project and adjacent grounds. All drops of potable or recycled water delivered to the project must be metered.

This category attempts to compare the total water usage of buildings with high-performing buildings. Personal communication was conducted with regular occupants

to check meters, examine the use of water and consumption quantities, and get water consumption bills to acquire information about water efficiency. The data received for the 12 months was uploaded into the Arcskoru online spreadsheet to achieve the water performance score (Figure 14). The Arcskoru scored 11 credit points out of 15.

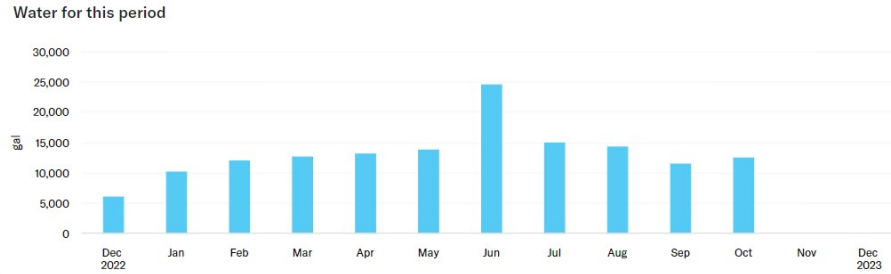


Figure 14: The total amount of water consumed by each occupant. Source: Author-based on Arcskoru website

4.5 *Energy and atmosphere*

The main objectives of the Energy and Atmosphere (EA) category are to encourage the implementation of renewable energy sources and optimize building energy performance. It consists of credits for increased energy efficiency, on-site renewable energy production, and steps to lower greenhouse gas emissions related to a building's energy use. The Tabriz residential building study only covers some EA credits as these topics do not concern civil engineers. However, it may still use part of the credits.

4.5.1 **Energy and Atmosphere: Energy performance**

Energy performance credit is a performance requirement that must be documented using the Arc platform. After inputting energy consumption data into the Arc platform, an energy performance score for a case study is generated automatically. The building's annual energy consumption data is equal to 100.17 MWh, and electricity bills for the past 12 months have been entered into the Arcskoru platform, which has generated a score of 10 out of 33 in the energy and atmosphere credit. Due to this

credit based on energy performance, Arcskoru calculates it out of 33 points instead of 35 (Figure 15).

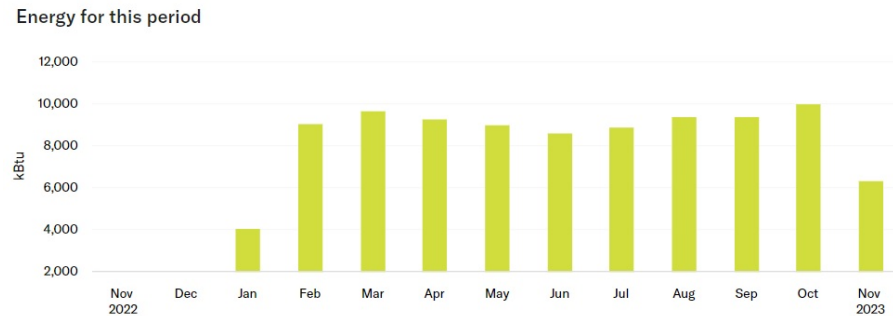


Figure 15: Energy consumption of the building in the last 12 months based on the bills. Source: Author-based on Arcskoru website

4.5.2 Energy and Atmosphere: Fundamental Refrigerant Management

According to the LEED v4.1 guide, only buildings will likely achieve this prerequisite with non-chlorofluorocarbon (CFC) central cooling systems. If the building is not in this category, pursuing accreditation may not make sense. In this case study, different devices with different refrigerants have zero ozone depletion potential (ODP). Therefore, this thesis could fulfill the prerequisite.

4.5.3 Energy and Atmosphere: Enhanced Refrigerant Management

The Enhanced Refrigerant Management credit is given to initiatives that may reduce the impact of their refrigerants on the ozone layer and global warming. There is one cooling system (air conditioning) on the fourth level in this case study; the air conditioner used in this building is O-General, and R410 is used as the gas. R-22, commonly referred to as Freon, is a chlorofluorocarbon (CFC), but R-410A is not. R32 and R410A are both members of the hydrofluorocarbon gas group. Because of their zero ODP, they are environmentally friendly. According to National Geographic's article "Ozone Depletion Facts," [46], CFCs are the chemicals that have harmed the

Earth’s ozone layer during the last many decades. R410A is a hydrofluorocarbon (HFCs) refrigerant that is regarded more environmentally friendly than R22.

Furthermore, the refrigerators have been inspected; their refrigerant is R600a, a natural and ecologically safe refrigerant. Table 5 shows the refrigerant of appliances such as air conditioner and fridge in the case study obtained from ASHRAE Standard 34. Therefore, the thesis could achieve 1 point from Enhanced Refrigerant Management credit.

Table 5: The appliance’s refrigerant in the case study

Floor	Appliance	Gas/Refrigerant	ODP
1	Fridge	R314A	0
3	Fridge	R600A	0
	Air conditioner	Air-conditioner	0
4	Fridge	R32, Fridge: R314A	0
5	Fridge	R410A	0

4.6 *Material and Resources*

This category tries to prevent damage to the environment caused by materials, waste, and purchased products and uses them during the operation and maintenance of the building. The case study lacked Facility Maintenance and Renovations Policy and Purchasing; only Purchasing Policy and waste performance requirements were met and calculated in the material and resources credit.

4.6.1 **Material and Resources: Purchasing policy**

In this prerequisite, it is necessary to identify five major building purchases to create a compliant purchasing policy and submit it to the US Green Building Council (USGBC) website to help the environment with preferred products. As a result, personal communication with regular residents was conducted to determine the top five

products shown in Table 6.

Table 6: Purchasing policy of Tabriz building

Ongoing purchasing of consumables

Food and beverage

Batteries

Kitchen Supplies

Toiletries

Cleaning Supplies

4.6.2 Material and Resources: Waste performance

It is essential to measure and compare the buildings' waste management efficiencies. This helps track and reduce the waste generated by building occupants. Typically, the lower the weight of waste created and the higher the diversion rate, the better the waste score in Arcskoru. Based on personal communication, the amount of waste produced by each unit per month has been entered in Arcskoru, and no waste diversion occurred in any unit.

The waste performance score is determined using the project's average daily waste produced per occupant and average daily waste undieted per occupant. The total amount of waste produced was between 254 kg and 307 kg per month. Since no waste was diverted, the building scored 3 out of 8 (Figure 16).

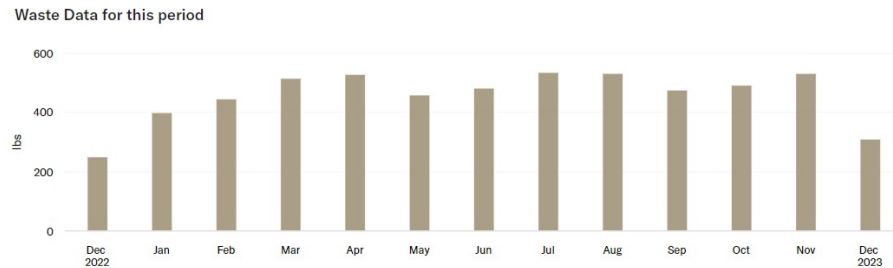


Figure 16: Waste generated. Source: Author-based on Arcskoru website

4.7 Indoor environment quality

Most people spend 90% of their time inside, making the building a healthy environment for the people who live in it will result in a better experience for the end user [47, 48]. The intention of Indoor Environmental Quality (IEQ) in LEED v4.1 is to establish interior spaces that contribute to occupant well-being and comfort by addressing components such as air quality, tobacco, and smoke control, and using green materials. It focuses on improving building environmental conditions to improve occupant health, productivity, and personal satisfaction.

Buildings with inadequate ventilation or particles in the air from construction materials can be hazardous for the environment, visitors, and occupants. The quality of the interior environment may be addressed in various ways. However, this section will concentrate on indoor air quality, environmental tobacco smoke control, green cleaning policy, and integrated pest management to achieve LEED credits.

4.7.1 Indoor Environment Quality: Minimum Indoor Air Quality Performance

It is necessary to achieve the prerequisite of Minimum Indoor Air Quality Performance naturally in ventilated rooms. In the case of residential units, the building must have an operable window in each bedroom, with a total Operable window area of at least 4% of the room floor space. This indicates that if the bedrooms in the Tabriz case study have floor areas of 13.2 sqm and 12.9 sqm, respectively, and the operable window area on the north side is 0.68 sqm, the operable window area is greater than 4% of the total floor area. These windows on the north sides of the building will enable airflow through the building to preserve air quality and climate regulation. As a result, this case study will fulfill the ASHRAE 62.1-2016 standards and IEQ prerequisite 1. Natural ventilation areas must have a minimum opening location and size (Table 7).

Table 7: Natural ventilation for residential units. Source: LEED O+M guidance

<i>Opening type</i>	<i>Area of location</i>	<i>Size of opening</i>		Maximum distance	>4% of floor area
		Area of window	Minimum opening area	from operable openings	
				5 x ceiling height (Only for common spaces like the living room)	
Double side	48.78 sqm	5.1 sqm	3.06 sqm	5 m x 2.8 m	1.95 sqm
Single side	13.2 sqm	1.35 sqm	0.675 sqm	4.4 m	>0.528 sqm
Single side	12.9 sqm	1.35 sqm	0.675 sqm	4.3 m	>0.516 sqm

4.7.2 Indoor Environment Quality: Environmental Tobacco Smoke Control

As environmental tobacco smoke (ETS) is a widely known human health danger. A no-smoking policy should specify all forms and sources of smoke that are covered by this prerequisite. The only way to completely get rid of the hazard of ETS is to entirely prohibit smoking within the building, which is why dedicated interior smoking areas are banned. Smoking is forbidden within 25 feet (7.62 meters) of building entrances, outside air intake, and operable windows in residential boundaries. If the team wants to create a smoking area, it must be at least 7.62 meters from building openings. The property owner or occupants must have strategies for communication in place to inform building users of the no-smoking policy. Personal contact was carried out, and there were no smokers among the residents. However, a no-smoking policy should be determined because there is no guarantee with visitors.

4.7.3 Indoor Environment Quality: Green Cleaning Policy

This prerequisite requires a clear policy to decrease chemical, biological, and particle pollutants that can endanger air quality, human health, building finishes, building systems, and the environment.

4.7.4 Indoor Environment Quality: Indoor Environment Quality Performance

This is a performance prerequisite that must be documented using the Arc platform. The requirement consists of an occupant satisfaction survey and indoor air quality testing. Each component combines to form a single "human experience" score.

- 1) Occupant's experience of building:

It is a performance prerequisite that must be stated utilizing the Arc platform. The tenant satisfaction survey was emailed to residents for rapid completion online (Figures 17).



Language: English ▼

1. Use the slider to indicate how satisfied you are with the environment in this building

Very Satisfied

Extremely Unsatisfied

Extremely Satisfied

2. We're glad to hear that. Please select the options below that significantly enhance your satisfaction:

☐ Thermal Comfort ☒ Sound ☐ Air Quality

☒ Cleanliness ☒ Light ☒ Privacy

☐ Views to Outdoors ☒ Daylight

Figure 17: Occupant satisfaction survey. Source: Author-based on Arcskoru website

- **2)Indoor Air Quality Testing:**

According to the definition provided by the US Environmental Protection Agency (EPA), volatile organic compounds, or VOCs, are group of organic chemical compounds that have a composition that allows them to evaporate in standard indoor air conditions, such as temperature and pressure. A compound's tendency to be released into the air from a product or surface increases with its volatility [49]. VOCs can occasionally be classified according to how easily they will emit. For instance, indoor organic pollutants are classified by the World Health Organization (WHO) [50] as:

- Very volatile organic compounds (VVOCs)
- Organic volatile compounds (VOCs)
- Organic chemicals that are semi-volatile (SVOCs)

The authors of this study take VOC into account for the IEQ credit.

Carbon Dioxide (CO₂) and the TVOC measurements must be conducted in the building to fulfill the indoor air quality prerequisite. These measurements were performed on the 10th of February 2023, and the 22nd of September 2023. For collecting indoor air measurements at places representative of all residential areas inside the breathing zone (between 900 and 1800 millimeters above the floor), during average occupied hours, and under typical minimum circulation conditions. According to LEED O+M guidelines, the minimum number of testing locations for each project is one on each building floor. Indoor air quality and occupant satisfaction are evaluated and combined into a single performance score. To measure TVOC and CO₂, a JLDG Air Quality Tester with the model number HBCV00000M7NCU was utilized. The measurements were taken one meter above the living room, kitchen, and bedroom floor.

On the 10th of February, the average CO₂ reading was 390.36 ppm; on the 22nd of September, it was 392.05 ppm. Furthermore, TVOC measures were considered

essential since they contribute to personal comfort, cleanliness perception, and health among occupants. In February, all informed TVOC values in indoor areas varied between 0.01 mg/m³ and 0.036 mg/m³, and in September, they ranged between 0.011mg/m³ and 0.024mg/m³. These values indicate that the inside spaces varied from good to excellent quality.

The LEED O+M guidelines recommend measuring TVOC once a year; however, in this case study, TVOC and CO₂ were measured twice to examine the variations in TVOC levels throughout winter and summer. Since windows may be kept open more often in the summer to allow for more airflow between the inside and outside of the building, windows may be kept closed for long periods during the winter. Furthermore, areas with open windows often have better ventilation rates since outside air may enter and lessen interior contaminants like VOCs. On the other hand, closed windows would need more mechanical ventilation, which might result in a slower airflow between the inside and outside of a space.

All measurements were submitted to the Arcskoru website, and human experience calculations were performed (Figure 18). As a result, the building earned 19 points out of a possible 22, although it still needs to get the two credit points for green cleaning and integrated pest management (Figures 19 and 20). Figure 21 and Tables 8 , 9, 10, and 11 and show the TVOC and CO₂ measurements on the 10th of February 2023 and 22nd of September 2023 of floor 4.



Figure 18: Satisfaction rating and feedback of residents' responses. Source: Author-based on Arcskoru website

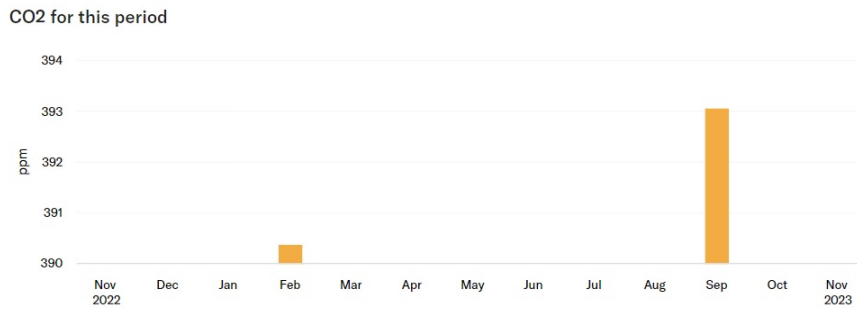


Figure 19: CO₂ emission on the 10th of February and on the 22nd of September. Source: Author-based on Arcskoru website

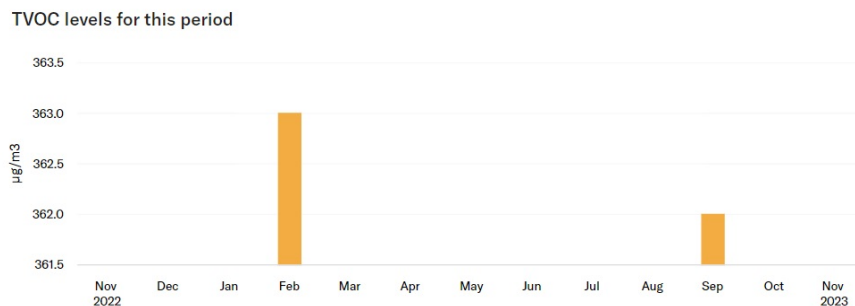


Figure 20: TVOC level on the 10th of February and on the 22nd of September.

Source: Author-based on Arcskoru website



Figure 21: TVOC and CO₂ measurements in February and September. (a): 10th of February 4th, 2023, floor kitchen (Left), 22nd of September 2023 4th floor kitchen (Left). (b): 10th of February 4th, 2023, floor Livingroom (Left), 22nd of September 2023 4th floor Livingroom (Left). (c): 10th of February 4th, 2023, floor Master bedroom (Left), 22nd of September 2023 4th floor Master bedroom. (d): 10th of February 4th, 2023, floor bedroom (Left), 22nd of September 2023 4th floor bedroom.

Table 8: TVOC level on the 10th of February 2023.

	<i>TVOC</i>				<i>Start and end time</i>
	<i>(mg/m³)</i>				<i>(s)</i>
Floor	Kitchen	Living room	Master Bed	Bedroom	
1st floor	0.017	0.016	0.021	0.011	13:47-13:56
2nd floor	0.015	0.013	0.015	0.036	13:39-13:42
3rd floor	0.021	0.022	0.024	0.024	13:32-13:40
4th floor	0.019	0.01	0.017	0.023	13:07-13:20
5th floor	0.018	0.024	0.016	-	13:22-13:27
parking	0.016				
Elevator	0.127				

Table 9: CO₂ amount on the 10th of February 2023.

	<i>CO₂</i>				<i>Start and end time</i>
	<i>(ppm)</i>				<i>(s)</i>
Floor	Kitchen	Living room	Master Bed	Bedroom	
1st floor	386	388	391	385	18:15-18:26
2nd floor	388	386	386	413	18:09-18:14
3rd floor	385	387	396	390	18:01-18:06
4th floor	407	385	393	385	17:46-17:56
5th floor	392	388	386	-	17:58-18:00
parking	298				
Elevator	514				

Table 10: TVOC level on the 22nd of September 2023.

	<i>TVOC</i>				<i>Start and end time</i>
	<i>(mg/m³)</i>				<i>(s)</i>
Floor	Kitchen	Living room	Master Bed	Bedroom	
1st floor	0.022	0.023	0.023	0.011	18:15-18:26
2nd floor	0.022	0.023	0.02	0.017	18:09-18:14
3rd floor	0.02	0.018	0.02	0.016	18:01-18:06
4th floor	0.018	0.019	0.019	0.017	17:46-17:56
5th floor	0.024	0.013	0.018	-	17:58-18:00
parking	0.019				
Elevator	0.038				

Table 11: CO₂ amount on the 22nd of September 2023.

	<i>CO₂</i>				<i>Start and end time</i>
	<i>(ppm)</i>				<i>(s)</i>
Floor	Kitchen	Living room	Master Bed	Bedroom	
1st floor	385	385	393	393	18:15-18:26
2nd floor	454	394	386	387	18:09-18:14
3rd floor	405	404	393	390	18:01-18:06
4th floor	385	387	385	385	17:46-17:56
5th floor	387	385	385	-	17:58-18:00
parking	297				
Elevator	405				

4.8 *Innovation*

In this category, projects can receive bonus points for using creative approaches and solutions that exceed LEED's basic requirements. By using innovation credits, projects can demonstrate innovative methods and technologies that improve the building's overall sustainability and environmental performance.

4.9 *Performing retrofit scenarios*

This research applies multiple retrofit scenarios to a residential building to earn an enhanced certification level in the LEED O+M program. The study attempts to improve the performance of buildings from operational and maintenance aspects to align with LEED criteria through an in-depth review of diverse retrofit strategies encompassing energy-efficient technologies, sustainable materials, and innovative practices. The following scenarios were considered to gain more points from those credits:

Scenario 1, which represents the current condition of the building with no modifications, has a total energy consumption of 101.3 MWh and a total CO₂ emission of 34437.89 kg. In this scenario, the building lost points from sustainable sites, energy and atmosphere, material and resources, and innovation credits.

Following these single scenarios, a combination scenario is created. The best solution from each is combined to create a combination scenario. With the help of various solutions, this all-encompassing strategy seeks to optimize energy savings, reduce environmental impact, and improve overall building efficiency. The combination scenario offers a comprehensive and dynamic retrofitting approach by combining the best possibilities found in the single scenarios, yielding better sustainability and energy efficiency results. Therefore, these scenarios show how the building can enhance its LEED certification by implementing minor technical changes. Retrofit scenarios must obtain scores from credits SS, EA, MR, IEQ, and innovation to receive a higher certificate from LEED O+M,. The following modifications are considered to earn

better points:

- Scenario 1: Current condition of the building with no modifications.
- Scenario 2: Applying photovoltaic panels (PV Panels) on the rooftop to generate electricity for the case study.
- Scenario 3: Replacing lighting fixtures with LED bulbs, which can help reduce energy consumption, lower heat emissions, are recyclable, minimize light pollution, and are mercury-free.
- Scenario 4: Applying external wall insulation can enhance the thermal efficiency of buildings, lowering heat loss in winter and heat gain in summer. As a result, energy usage for heating and cooling is decreased, leading to energy efficiency and reduced greenhouse gas emissions [30].
- Scenario 5: Replacing windows with Double-glazed windows. They may minimize noise pollution, boost security, improve appearance, and improve occupant comfort.
- Scenario 6: Light-colored roof materials with SRI value help to reduce the Heat Island effect by reflecting more sunlight, lowering heat absorption, and harmonizing with LEED sustainability standards.
- Scenario 7: Controlling waste performance and diverting them separately by asking occupants.
- Scenario 8: Changing the direction of external lighting devices and covering them with a shield can reduce light pollution.
- Scenario 9: A combination scenario.

CHAPTER V

RESULTS

Annual and monthly simulations were done for each scenario, and sustainable retrofitting solutions were evaluated within the scope of the study. These retrofit solutions include solar panel installation, LED replacement, external lighting implementation, exterior insulation of walls, replacement of single-glazed windows with double windows, consideration of light color for the roof to reduce the heat island effect, and waste performance control.

Case study analyses have been performed for the Tabriz, Iran, residential building. Most common retrofit options have been considered for this study. The necessary construction and architectural details are provided by material specifications derived from the drawings. After that, relevant scenarios were applied to the case study building, and energy analyses were conducted for each scenario. The scenarios' End-Use Consumption (EUC) and CO₂ emissions are carried out step-by-step and compared with the case study before retrofitting. The word "EUC" stands for "end-use consumption," which describes how much energy is ultimately used by end users for specific uses like electricity, natural gas, heating, and lighting.

5.1 The results of existing building' energy analyses in Tabriz

Figure 22 shows the annual EUC of the case study building in Tabriz before retrofitting. As it is clear from Figure 22, the highest consumption is related to natural gas and electricity. They account for 46% and 26% of total energy consumption. The annual energy usage of the studied building is equal to 101.302 MWh. Natural gas has a yearly consumption of 64,408.61 kilowatt hours, and electricity consumption equals 36,893.46 kilowatt hours.

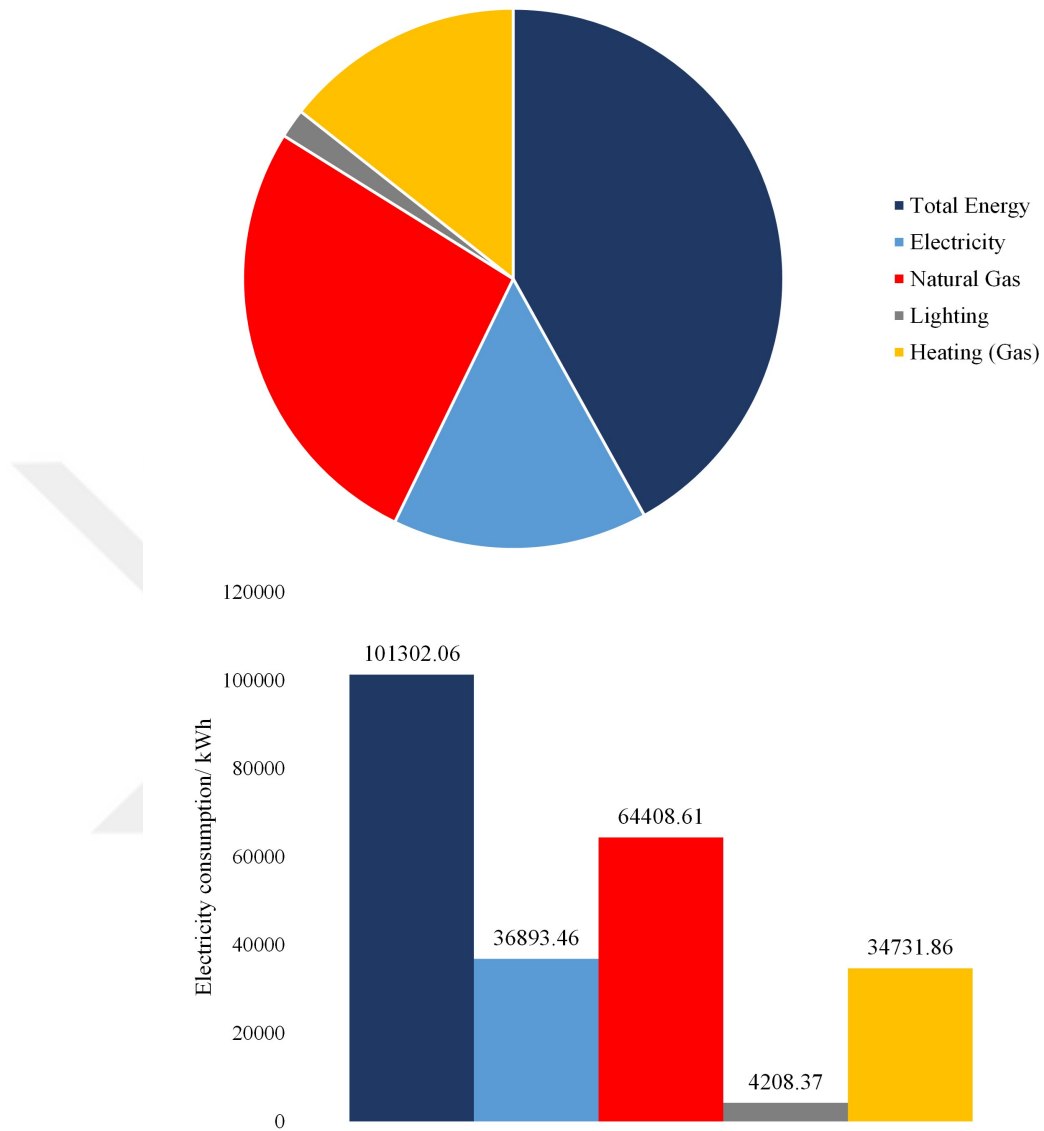


Figure 22: Annual EUC of the case study building before retrofitting in scenario 1

5.2 *CO₂ emission result of existing building and scenarios*

Numerous factors, including the occupancy schedule, the availability of natural light, and construction materials, affect a building's CO₂ emissions. These factors also affect how much a facility's emissions vary year over year. Figure 23 displays the CO₂ emissions of the case study both before and after retrofitting. Before retrofitting, CO₂ in the existing building was 34437.89 kg; however, by applying several scenarios, this amount decreased dramatically. In scenarios 2 and 9, CO₂ emissions were significantly reduced by 33% and 51%, respectively.

The calculation of EUC and CO₂ emissions within the DesignBuilder software was shown to be unachievable in scenarios 7 and 8. As a result, the authors had to manually enter the data for scenario 7 into the Arcskoru website. As a result of this approach, the values for EUC and CO₂ in scenarios 7 and 8 should be included in the study's Figures and Tables

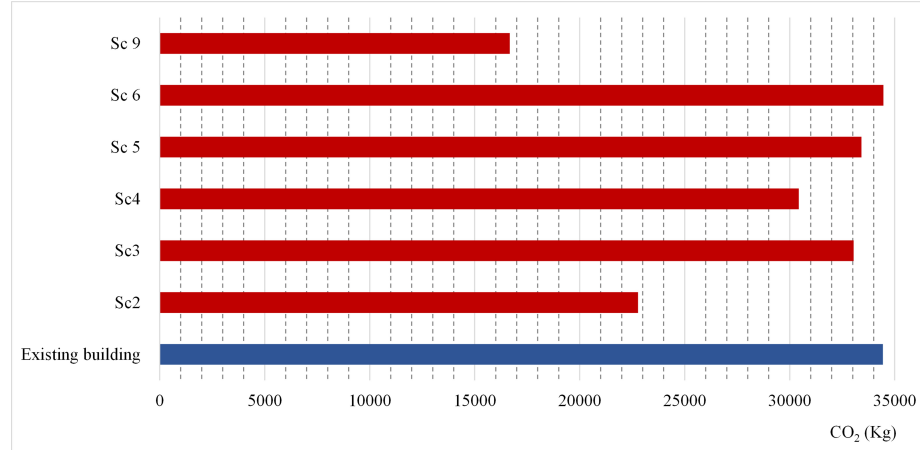


Figure 23: CO₂ Emission per year in different scenarios

5.3 Scenario 2: PV panels

Based on its location, Tabriz City has an excellent need for domesticating solar energy because of its climatic situation and geographical position [44]. Choosing the best tilt angle for PV panels in Tabriz, Iran, requires considering the location's latitude and sun position variations. Tabriz's latitude is roughly 38 degrees north. Setting the tilt angle roughly equal to the latitude is a suitable starting point for optimal yearly energy output, according to basic solar panel tilt angle guidelines. Based on (Jacobson MZ et al. 2018) [51] and the Solargis website, the optimum tilt of PV modules in the Tabriz location is 34 degrees [52, 53].

PV panels, or renewable energy sources, can help buildings minimize their reliance on electricity and carbon emissions. Figure 24 depicts Iran's substantial potential for solar energy use [53]. As a result, the solar system design and simulation exercise was carried out on the Tabriz case study with PVSOL® premium 2021 software. Users may work on 2D or 3D models with the PVSOL® application. The 3D design option, on the other hand, enables the creation of a 3D model of building geometry, including roof parts and PV modules.

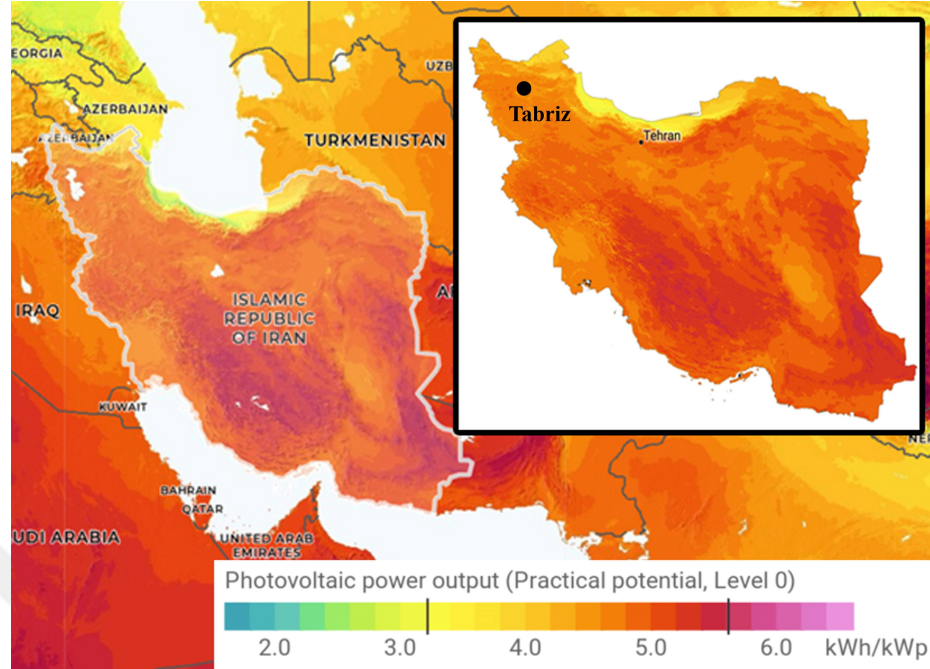


Figure 24: Iran's photovoltaic power potential.

[53]

For the case study's southern orientation, 27 panels with module dimensions of 1000 millimeters x 1626 millimeters were determined, and the slope was analyzed at an optimum slope angle of 34 degrees. Table 12 summarizes the key characteristics associated with PV panels. Annual energy consumption in this scenario is 82.84 MWh; compared to case studies of yearly energy consumption before retrofitting, which is 101.3 MWh, there is a total decrease of 18.21% (Figure 25). As shown in Figure 25, the PV panels in this scenario generated 17,681.994 kWh of electricity by converting sunlight into electricity. PV panels were applied to the rooftop to improve the EA scores in LEED v4.1 O+M and enhance energy performance credit points.

As seen in Figure 26, PV panels generate more electricity during the summer months of June to August than during the winter months, owing to more sunshine and longer daylight hours. The seasonal change in sun intensity adds to a significant difference in energy output, with summer defined by the perfect conditions for

photovoltaic conversion.

Table 12: PV panel feature

<i>Manufacturer</i>	<i>ASSolar</i>
<i>Module type</i>	AS Seginus SE M (230 Wp)
<i>Cell type</i>	<i>Si – Monocrystalline</i>
<i>Value source</i>	<i>Meteonorm 8.2</i>
<i>Efficiency</i>	14.31%
<i>Nominal output</i>	230W
<i>Number of PV modules</i>	27
<i>Number of Invertors</i>	1
<i>PV generator output</i>	8.21(kWp)
<i>Width</i>	1000(mm)
<i>Height</i>	1626(mm)
<i>Depth</i>	35(mm)
<i>Specific CO₂ saving through use of PV energy</i>	479(g/kWh)
<i>Performance ratio</i>	80.47%
<i>Orientation</i>	180Degree

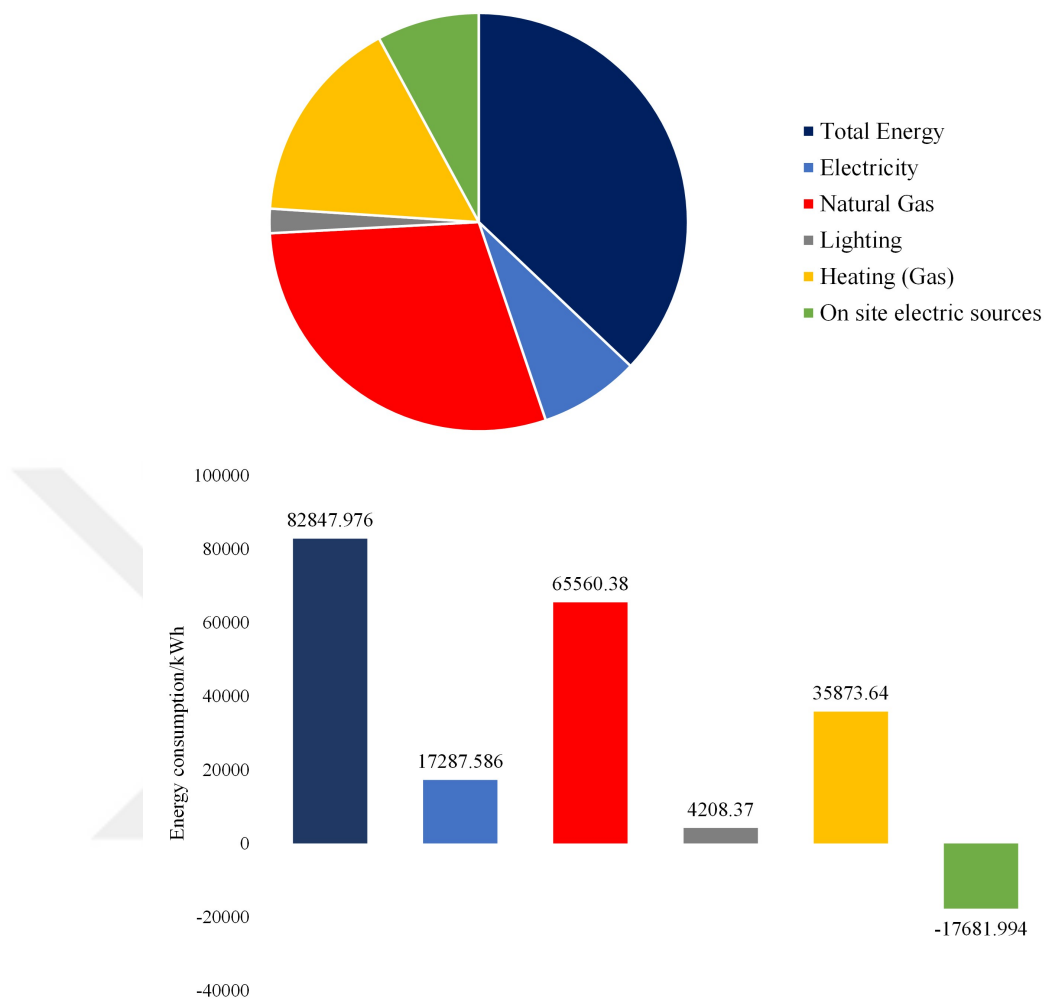


Figure 25: Annual EUC of the case study building for scenario 2.

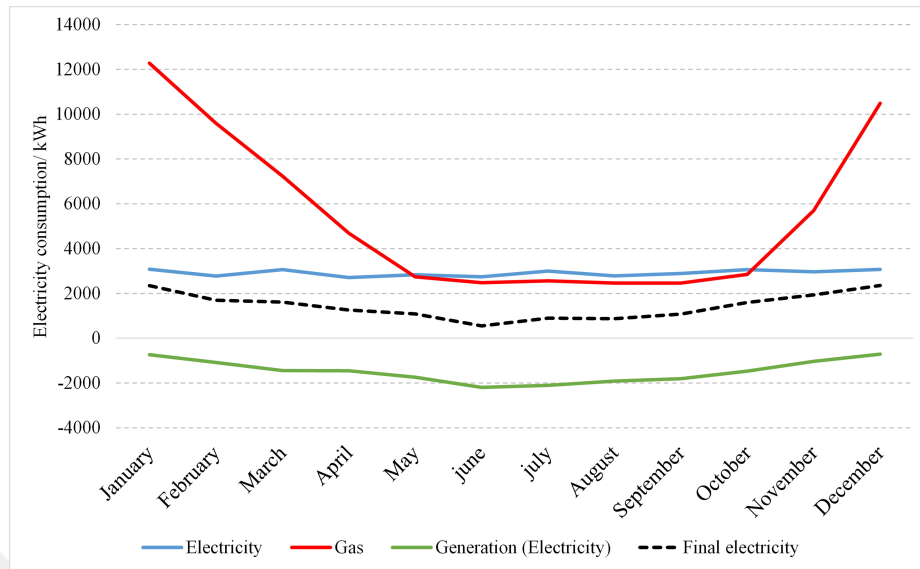


Figure 26: Total fuel consumption of scenario 2.

5.4 Scenario 3: Replacing lighting fixtures.

All Compact Fluorescent Lamps (CFLs) are replaced with light-emitting diodes (LEDs) to enhance the lighting system. Retrofitting lighting fixtures is a simple way to improve the energy efficiency of a building. There are several benefits to replacing CFLs with LEDs, which improve lighting performance overall and energy efficiency. Above all, LEDs use less energy than CFLs, using less electricity to produce an equivalent or even greater light level. This results in decreased energy usage and electricity prices, promoting environmental sustainability. Moreover, LEDs last longer than CFLs, requiring less maintenance and less replacement over time. Furthermore, LEDs are safer to dispose of and more ecologically friendly than CFLs, as LEDs are mercury-free. Figure 27 shows the result of replacing CFLs with LEDs, which reduced lighting consumption from 4208.37 kWh to 1989.25 kWh with more than 50% improvement in lighting. The total EUC energy consumption was reduced from 101.3 MWh to 98.83 MWh. Lighting fixtures have been replaced with LEDs to improve energy performance points in Energy and Atmosphere criteria in LEED.

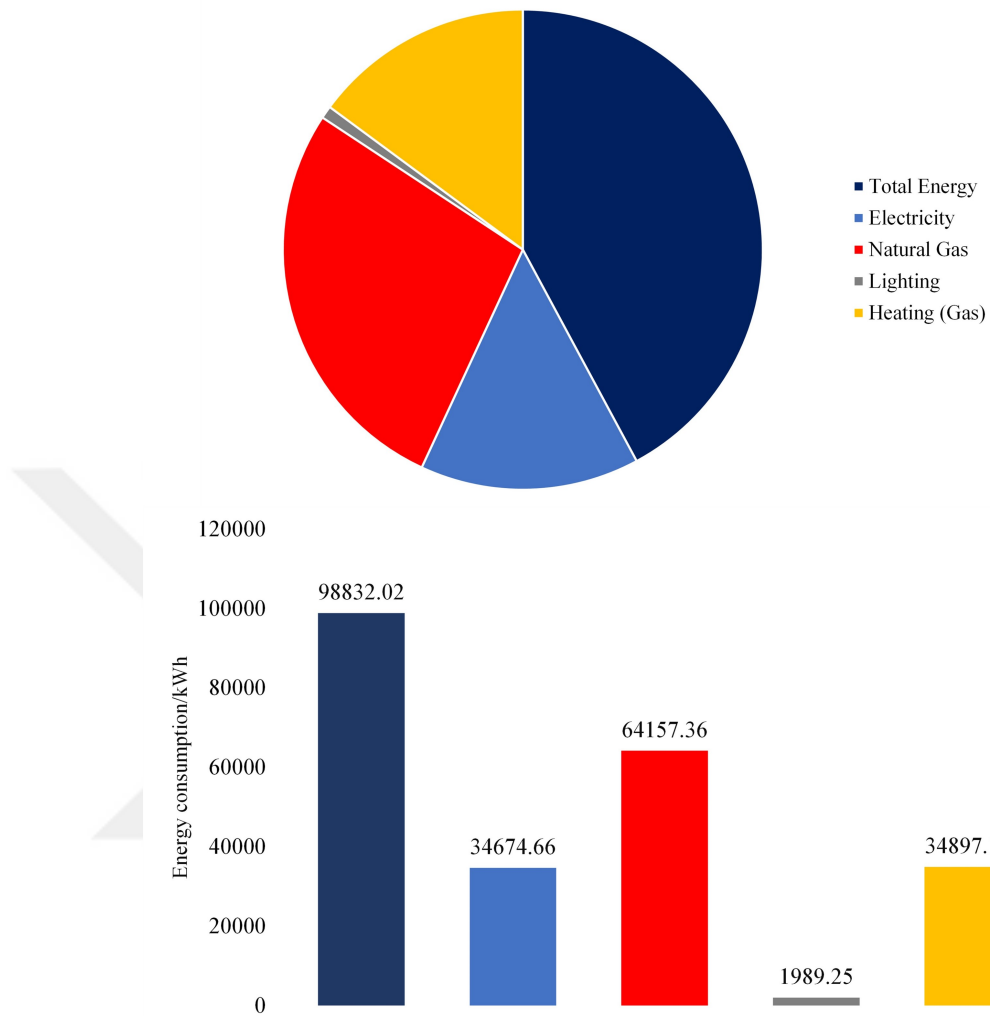


Figure 27: Annual EUC of the case study building for scenario 3.

5.5 Scenario 4: External wall Insulation

An infrared thermal camera helps to determine thermal bridges during energy retrofit. It offers quantitative and visual information that could be utilized to prioritize methods for reducing energy use, distributing resources effectively, and creating a thorough building energy improvement plan. Building performance can often be continuously monitored with the help of infrared cameras. Frequent thermal imaging examinations can assist in detecting variations in thermal patterns over time, suggesting possible problems that require treatment. Therefore, the UNI-T UTi85A Infrared Thermal Camera has been used for this thesis to locate and cover areas that are missing or have poor insulation.

Figure 28, taken by the UNI-T UTi85A Infrared Thermal Camera in two distinct seasons, shows the inside thermal bridge of the living room and the bedrooms from inside the building. Figure 28 shows a temperature color scale with the highest and lowest temperatures on the right side of the thermal photos the thermal camera took. Temperature readers in Figure 28 show 27.6, 26.3, and 21.8 degrees in the living room and bedrooms, respectively, with yellow and orange commonly used to represent warmer and higher temperatures than the surrounding areas. Yellow refers to potential spots of heat leakage or inadequate insulation, thermal bridges, and gaps that enable excess heat to enter the building. Detecting those areas and applying external wall insulation could improve energy efficiency and thermal performance.

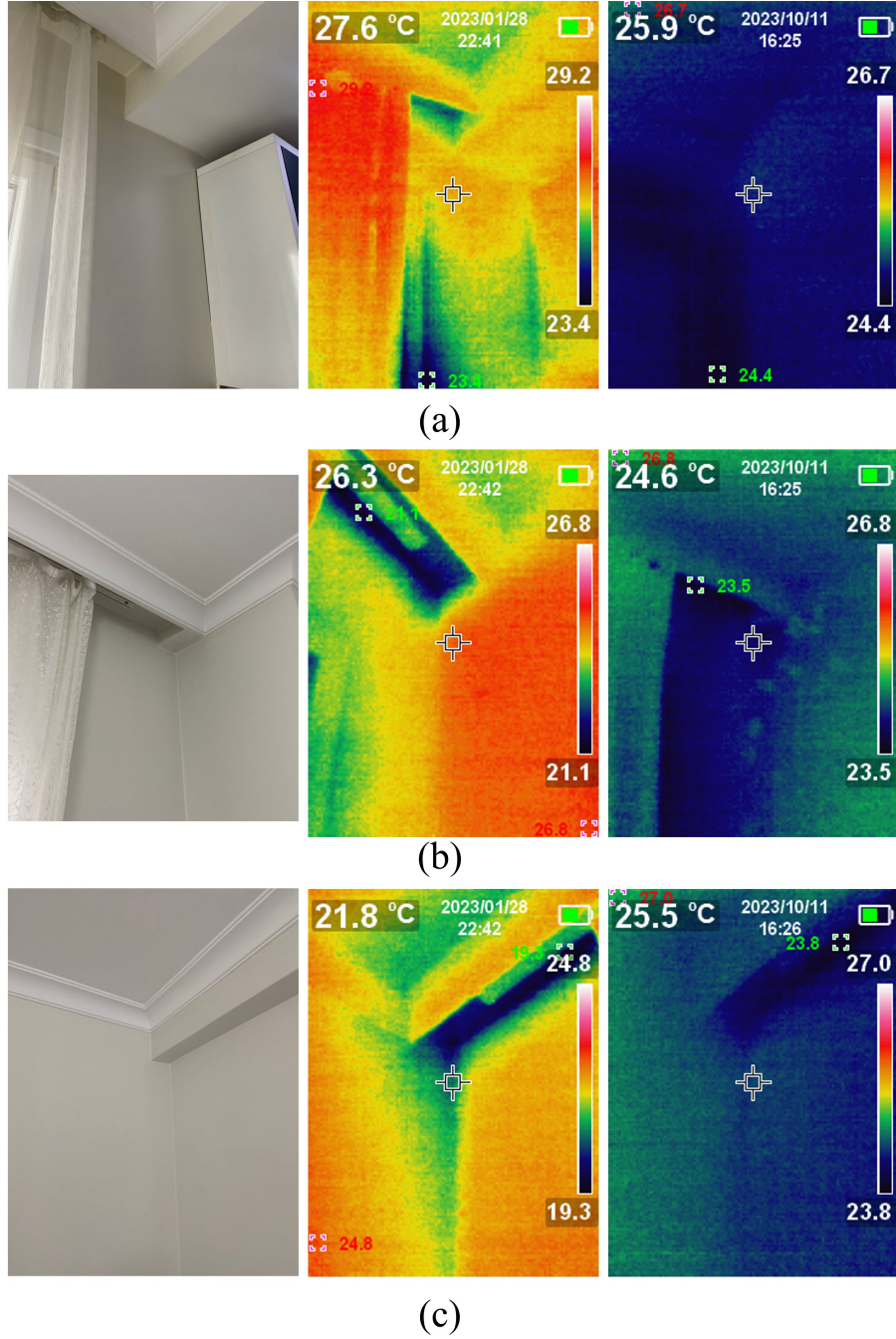


Figure 28: Thermal bridge of the (a) Living room, (b) master bedroom, and the (c) bedroom from inside the building in two distinct seasons.

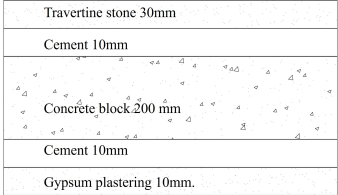
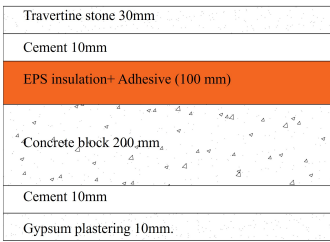
For external walls, the Maximum U-value in Topic 19 of the Iranian National Building Regulations is 0.8 W/sqm.K [54]. An additional layer of expanded polystyrene

(EPS) insulation with a conductivity of 0.035 (W/m-K) was taken into consideration for the external walls in scenario 4. Wall configurations for scenario 4 are displayed in Table 13.

This study has chosen EPS insulations, a common and/or available construction material in Iran [54]. Table 13 shows the wall configuration described here, considered in this thesis. It is one of the most widespread walls typical in the building sector of Iran.

In Table 13, it is shown that the heat loss from the wall was -9.05 kW before insulation and -2.14 kW after insulation. The improvement from -9.05 kW to -2.14 kW implies that the wall's thermal performance has improved following insulation. A smaller negative value indicates less heat escapes the wall. This is a good development since it shows that the insulation reduces heat loss and increases the building's energy efficiency. Figure29 shows the result of DesignBuilder software, which shows that the annual EUC of scenario 4 equals 82.11 MWh, with more than 18% improvement in total.

Table 13: The difference between wall layers before and after applying scenario 4.

	Before retrofitting	After retrofitting
		
U-value	1.554 (W/sqm-k)	0.286 (W/sqm-k)
Annual EUC	101302.06 (kWh)	82116.49 (kWh)
Improvement	0	18.93%
Heat loss of exterior wall	-9.05 (kW)	-2.14 (kW)

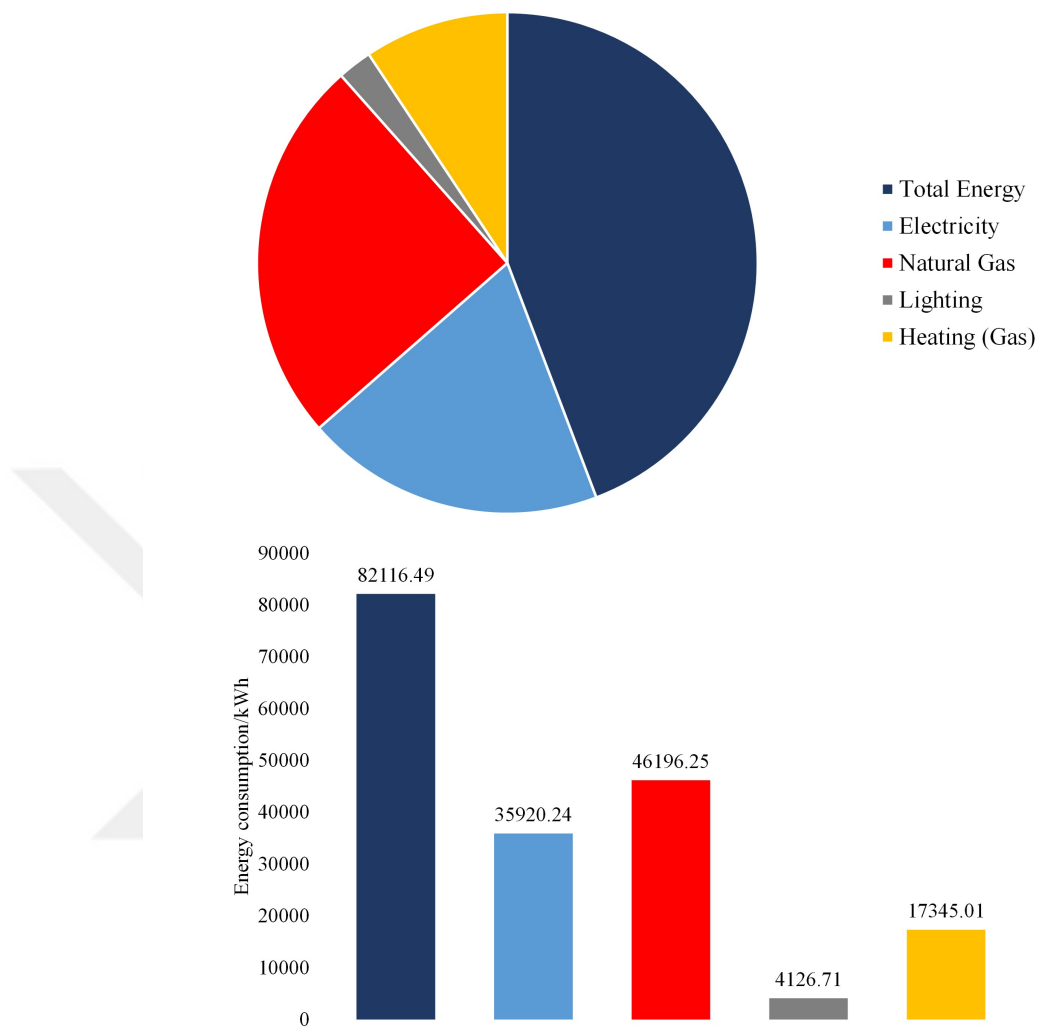


Figure 29: Annual EUC of the case study building for scenario 4.

5.6 Scenario 5: Replacing windows

Single-glazed windows offer less insulation and increase energy usage. In the winter-time, they let in more heat, which means that heating efforts must be increased to keep the interior at a suitable temperature. Similarly, single-glazed windows allow more heat to enter during warm weather, increasing the need for air conditioning to stay comfortable. On the other hand, double-glazed windows, which have two glass panes separated by a sealed layer, use much less energy. The sealed space's insulating properties reduce heat transmission. As a result, less energy is used for heating and cooling, reducing energy consumption. Since double-glazed windows can help reduce heating and cooling by up to 40%, in the case study, the double-glazed window with a 13 mm Argon gas and a Poly Vinyl Chloride (PVC) frame was replaced with a single-glazed window (Table 14). As shown in Figure 30, the total annual EUC of the case study in scenario 5 equals 95.87 MWh, which means 5.35% improvement.

Table 14: Window type for Scenario 5

<i>Component</i>	<i>Uvalue(W/sqm - k)</i>
<i>Doubleglazedwith13mmArgongas</i>	1.493
<i>20mmPVC - ISO10456</i>	3.476

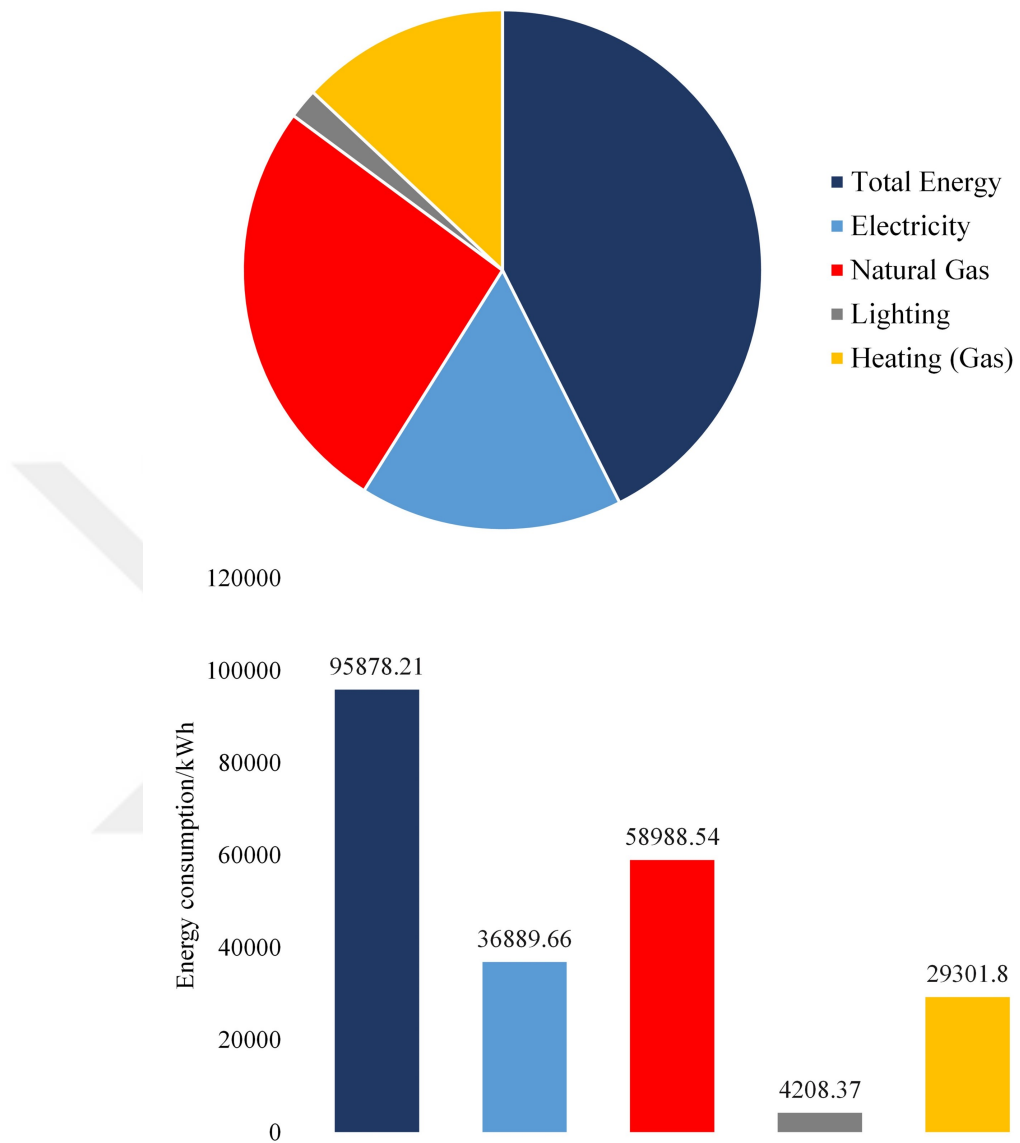


Figure 30: Annual EUC of the case study building for scenario 5.

5.7 Scenario 6: HEAT ISLAND- Sustainable sites

There are several ways to get 1 point from Heat Island Reduction Credit. This case study chooses light-colored roof materials with Solar Reflectance Index (SRI) value to improve energy consumption. Therefore, in this case study, the pavement of the site was covered with vegetation, and the roof material was changed to a light color with the amount of SRI. PV panels are also intended for the roof to generate electricity, cover the roof surface, and provide some shade.

The Solar Reflectance Index is utilized to meet LEED standards and determined with reflectance and emissivity values according to ASTM E 1980. The ability of the material to release absorbed energy is referred to as emissivity. A reflective roofing material with 1.2 (W/m-K) thermal conductivity and 2300 (kg/m³) density was chosen from CIBSE guidelines to satisfy LEED criteria. Table 15 shows the roof coating characteristics that were chosen.

The result in Figure 31 shows that changing the roof color to a lighter hue in the Tabriz case study is pointless, as overall, EUC increased from 101.3 MWh to 101.42 MWh in scenario 6. However, because this credit was allocated to the building, this case study could receive 1 point for heat island reduction.

Table 15: Reflective roofing material. Source: CIBSE Guide A, Table 3.36

<i>Material</i>	<i>Thermal conductivity</i>	<i>Density</i>	<i>Specific heat</i>
<i>Asphalt, reflective coat</i>	1.2(W/m – K)	2300(kg/m ³)	1700(J/kg – K)

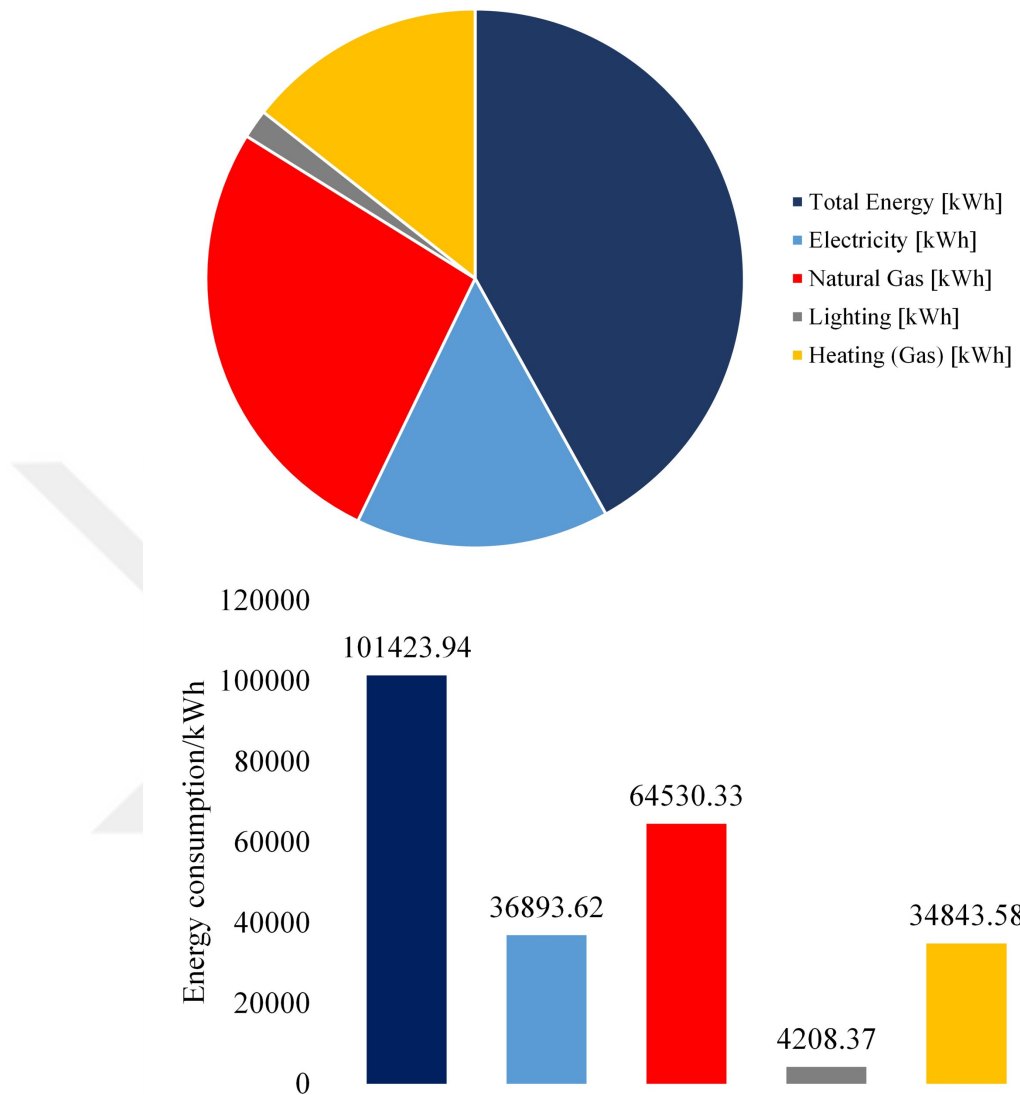


Figure 31: Annual EUC of the case study building for scenario 6.

5.8 Scenario 7: Waste performance

Because the smaller the weight of waste generated and the greater the diversion rate, the better the waste score in Arcskoru, the authors encouraged occupants to divert and report their waste amount. This data provided by tenants for 6 months was inputted into the Arcskoru, and this thesis earned 7 out of 8 waste performance credits to increase material and resource scores. Also, the amount of waste decreases drastically.

5.9 Scenario 8: Light pollution reduction

There are no outside lighting fixtures on the north side of the building; however, there are four lighting fixtures in the backyard with no fixture shielding. Therefore, in scenario 8, all exterior lighting fixtures are protected such that no light is directly emitted at a vertical angle of more than 90 degrees from straight down. In other words, four lighting shielding has been considered for the backyard lighting fixtures. As a result, this case study could achieve 1 point for reducing light pollution.

5.10 Scenario 9: Combined scenario

All the previous stable scenarios have been combined and merged in the ninth scenario to get the best achievable result. This method facilitates the development of different scenarios to address the optimization of energy consumption. The combination of different scenarios provides a dynamic framework for developing robust and flexible responses to complex energy consumption problems in an ever-evolving world.

Before retrofitting, the windows and exterior walls of the case study building experienced consequential heat loss of -3.82 kW and -9.05 kW, respectively (Figure 32). Single-pane windows allow heat energy to escape quickly. However, following the retrofitting approach, which included installing double-glazed windows and improving exterior wall insulation, the heat loss from the glass and wall decreased to -1.26 kW and -2.16 kW, respectively. This improvement improves the overall energy efficiency of the building and contributes to a more pleasant and sustainable indoor environment, demonstrating the positive impact of retrofitting measures on thermal performance.

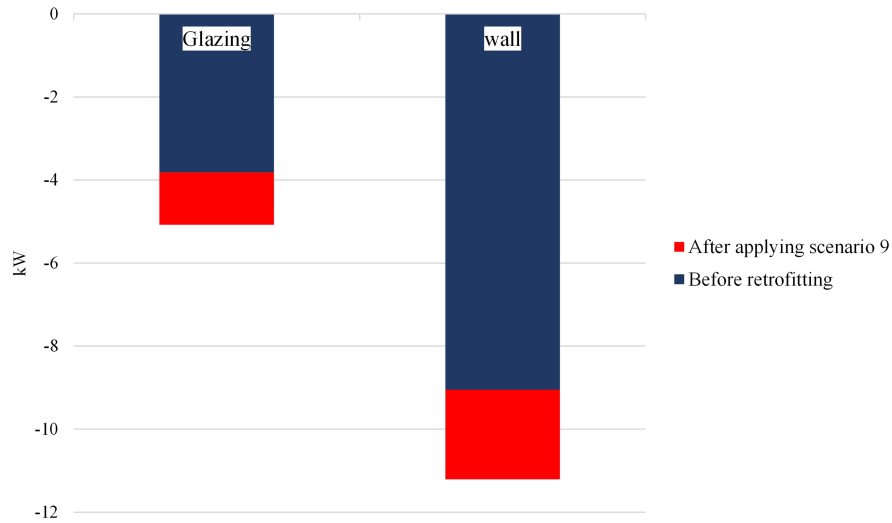


Figure 32: Heat loss of wall and glazing before and after retrofitting.

The annual EUC for implementing scenario 9 to the case study is displayed in Table 16 which shows that EUC is reduced to 56.98 MWh from 101.3 MWh. In

addition, Tables 16 and 17 provide an overview of the details of the selected scenarios and their application result to the building. Because of the installation of PV panels, electricity consumption in scenario 9 decreased by more than 60% to 14165.676 kWh from 36893.46 kWh. This scenario can reduce energy use by 43.71% overall, which would significantly decrease in sustainable building.

Table 16: Summary of results for all scenarios

<i>Sc</i>	<i>EUC</i>	<i>Electricity</i>	<i>Lighting</i>	<i>Natural gas</i>	<i>On – site generation</i>	<i>Improvement</i>
	(<i>MWh</i>)	(kWh)	(kWh)	(kWh)	(kWh)	(%)
<i>Sc1</i>	101.3	36893.46	4208.37	64408.61	0	-
<i>Sc2</i>	82.848	17257.586	4208.37	65560.38	17681.994	6.19
<i>Sc3</i>	98.832	34674.66	1989.25	64157.36	0	2.4
<i>Sc4</i>	82.116	35920.24	4126.71	46196.25	0	18.93
<i>Sc5</i>	95.878	36889.66	4208.37	58988.54	0	5.35
<i>Sc6</i>	101.42	36893.62	4208.37	64530.33	0	−0.12
<i>Sc9</i>	56.983	14165.676	1950.66	42817.4	17681.994	43.74

Table 17: Scenarios with technical information of materials used.

<i>Scenario code</i>	<i>Parameter</i>	<i>Currentstate</i>	<i>Improvement evaluated</i>
Sc1	Existing building		
Sc2	PVpanels		
Sc3	Lighting fixtures	CFL, Normalized power density: 5.00 (W/sqm -100 lux)	LED, Normalized power density: 2.5 (W/sqm - 100 lux)
Sc4	External wall insulation		100mm EPS insulation R-Value: 0.1500 (sqm -K/W)
Sc5	Window	Single glazing, clear, no shading with Aluminum frame	Dbl Low-E (e2=.1) Clr 6mm/13mm Arg, with Polyvinylchloride- ISO 10456
Sc6	Heat island	Asphalt	Reflective coat,R-Value: 0.1500 (sqm -K/W), Source: CIBSE Guide A (2006)
Sc7	Waste performance		
Sc8	Light reduction		90 Degree
Sc9	Combination	-	Sc2, Sc3, Sc4, Sc5, Sc6, Sc7, Sc8

Table 18 shows that using retrofit solutions based on LEED v4.1 O+M to reduce building energy consumption and CO₂ emissions has a positive effect. Given Tabriz's severe climate and frigid winters, scenarios 2, 4, and 9, which comprise exterior insulation, PV panels, and a combined scenario, are the best retrofit solutions to minimize energy use. As a result, this research demonstrates that using an exterior insulating layer and installing PV panels could benefit Tabriz's Climate.

Table 18: Summary of LEED Credits earned in case study.

LEED credits	Maximum point possible to earn	Project earned before retrofitting	Project earned after retrofitting
Location and Transportation	14	14	14
Sustainable Sites	4	1	3
Water efficiency	15	11	11
Energy and Atmosphere	35	10	30
Material and Resources	8	3	7
Indoor Environment Quality	22	19	19
Innovation	1	0	0
Total	100	58	73

Implementing LEED v4.1 for Operations & Maintenance: Existing Buildings for the Tabriz residential building, receiving 73 points out of 100 via the Arcskoru website, represents a significant dedication to sustainable and environmentally conscious building methods. Before using energy scenarios, this case study could receive a score of 58 out of 100 (Table 18).

Table 18 shows the effect of credits obtained before and after implementing energy and sustainability scenarios in a case study. This notable result represents a holistic approach to green construction solutions, including energy efficiency, water efficiency, indoor environmental quality, and resource management. A few prerequisites, grid harmonization for energy and the environment, green cleaning policy, integrated pest management for interior environmental quality, and the requirement to employ an authorized LEED expert for innovation, is out of the scope of the study.

The 73-point success shows the building's extensive integration of renewable energy sources. The LEED certification highlights the project's environmental responsibilities and adds to its residents' general well-being and comfort. By implementing the LEED v4.1 standards, the Tabriz residential building demonstrates a sustainable role in development. It proves its dedication to lowering environmental impact while encouraging a healthier and more resilient place. As a result, the Tabriz case study has a high potential for gold LEED certification under LEED v4.1 for Operations & Maintenance: Existing Buildings.



CHAPTER VI

DISCUSSION

Iran's inexpensive energy subsidies and water and electricity prices have increased constructing conventional residential buildings, emphasizing the necessity for energy-saving retrofits. Improving building energy efficiency is critical because the residential sector contributes enormously to Iran's rising global energy consumption. However, finding the appropriate retrofit method in Iran is difficult due to the country's unique characteristics, such as subsidized energy costs and water, and electricity prices. Thus, the purpose of this study is to (1) retrofit a five-story residential building implementing LEED v4.1 Operations and Maintenance (O+M) and (2) compare the resource consumption and carbon emission release of current conventional buildings with those of sustainable retrofitted buildings. DesignBuilder software has been used in this study to assess a residential building's energy, water, and lighting performance and carbon emission rate.

In total, nine scenarios were conducted in the case study. Analyzing the most effective scenarios for the existing building shows that, of the nine scenarios that were developed to improve the building's energy efficiency, the ninth scenario—which includes all the single scenarios shows a notable improvement, surpassing a 43% increase in efficiency in operations to achieve the best result in energy consumption and certificate in LEED v4.1 O+M.

Figure 33 shows the crucial findings from analyzing all scenarios in the Tabriz, Iran case study. As shown in the Figure, the building's end-use consumption before retrofitting was 101.3 MWh; however, after implementing efficient retrofit solutions, this value dropped to 56.98 MWh in the combined scenario 9. Because Tabriz often

has sunny summers, it is an ideal location for producing solar energy; therefore, in scenario 2, the total end-use consumption of the building was lowered by more than 6% to 82.84 MWh. Those PV panels could generate 17681.994 kWh per year, enough to cover buildings' 6 percent electricity use.

In scenario 3, when replacing LEDs with CFLs, lighting consumption is reduced from 4208.37 kWh to 1989.25 kWh, a more than 50% reduction. The total EUC of scenario 3 was 98.832 MWh. LED lighting surpasses CFLs in energy efficiency, with a more excellent lumens-per-watt ratio and a longer lifespan. Furthermore, LEDs contain no harmful chemicals such as mercury, reducing environmental worries and making them a more sustainable and environmentally sound lighting alternative.

Scenario 4 considers the installation of external insulation, particularly EPS, on exterior walls in the cold climates of Tabriz. Applying 100 mm EPS as an outer insulation material has substantial implications for improving building thermal performance. Using EPS insulation provides an outstanding barrier against heat transmission, lowering energy consumption for heating and cooling. Furthermore, installing EPS in external insulation systems improves the overall energy efficiency of structures, potentially resulting in cost savings and environmental advantages. The installation of external EPS insulation on the exterior wall of scenario 4 resulted in a significant improvement, with the reduction of wall heat loss from -9.05 kW to -2.16 kW, indicating the effectiveness of EPS in significantly improving thermal performance. In addition, the overall EUC of the case study decreased by more than 18% from 101.3 MWh to 82.116 MWh. In addition, the UNI-T UTi85A Infrared Thermal Camera is used in this thesis to identify thermal bridges throughout the building methodically.

Scenario 5 replaced the single-glazed and double-glazed windows filled with 13mm Argon gas with a Polyvinylchloride frame. The analysis shows more than a 5% reduction in energy consumption, and the total EUC of scenario 5 was 95.878 MWh, which decreased from 101.3 MWh in the existing building.

In scenario 6, light-colored roof materials with a high SRI value are considered for the building to help achieve the LEED Heat Island credit. To meet LEED standards, a reflective roofing material with a thermal conductivity of 1.2 (W/m-K), density of 2300 (kg.m³), and Specific heat of 1700 (J/kg-K) was selected from CIBSE Guide A, table 3.36. Scenario 6 demonstrates that in the Tabriz case study, altering the roof color to a lighter shade is ineffective since overall EUC increased from 101.3 MWh to 101.42 MWh in scenario 6. Because this credit was assigned to the building, this case study could earn 1 point for heat island reduction.

Before retrofitting, this case study scored 3 out of 8 in waste performance of LEED v4.1 O+M. To improve and achieve a better score in waste performance credit in scenario 7, personal communication with residents has been conducted to reduce and record waste diversion since June 2023. Therefore, the authors have entered these data into Arcskoru, and this case study could achieve 7 points out of 8. Compared to June, these differences significantly impacted waste production and diversion.

Since light pollution is a concern, LEED v4.1 O+M urges projects to include efficient lighting strategies that eliminate unnecessary artificial light. Thus, scenario 8 considers including shielded lights for outside lighting. All four exterior lighting fixtures have been shielded to prevent any light from being reflected directly at an angle greater than 90 degrees from the downward direction. This case study can thus be awarded one point for reducing light pollution.

By comparing the results of the several retrofit scenarios in Tabriz, Iran, located in the cold climate, it is clear that the most sustainable and efficient retrofit solution to decrease the energy consumption and CO₂ of the five-story residential building based on the LEED v4.1 O+M Existing building is the combination of efficient single scenarios represented in Figure 33.

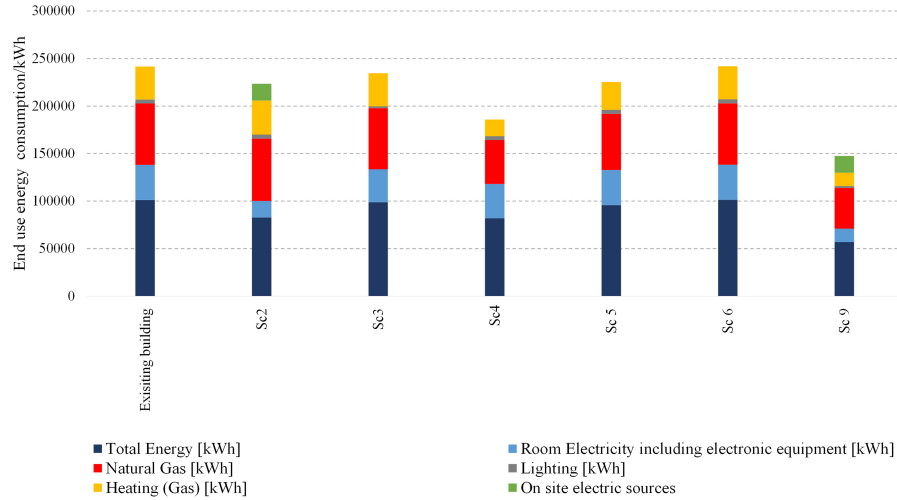


Figure 33: Annual EUC of the case study building for scenario 9

Figure 34 presents the LEED v4.1 O+M checklist applied in the case study. Regarding the existing building's performance checklist of LEED v4.1 O+M, the Tabriz case study was evaluated, and points were considered based on its location in the city center. The building's average one-way route was 2 kilometers; therefore, the Tabriz case study earned 14 points out of 14 in the categories of location and transportation. To rate the building's distance from work in one of two ways, Arcskoru emailed a questionnaire to the occupant. The building also obtained three out of four points for the Sustainable Sites category by applying scenarios 6 and 8.

		LEED v4.1 for Operations & Maintenance: Existing Buildings		Project Name: Residenatil building in Tabriz, Iran	
		Project Checklist		Date: 2022-2023	
Y	?	N			
14	0	0	Location and Transportation	14	
14			Credit Transportation performance	14	
3	0	0	Sustainable Sites	4	
1			Credit Rainwater Management	1	
1			Credit Heat Island Reduction	1	
1			Credit Light Pollution Reduction	1	
0			Credit Site Management	1	
11	0	0	Water Efficiency	15	
11			Prereq Water Performance	15	
30	0	0	Energy and Atmosphere	35	
Y			Prereq Energy Efficiency Best Management Practices	Required	
Y			Prereq Fundamental Refrigerant Management	Required	
29			Credit Energy Performance	33	
1			Credit Enhanced Refrigerant Management	1	
0			Credit Grid Harmonization	1	
7	0	0	Materials and Resources	9	
Y			Prereq Purchasing Policy	Required	
Y			Prereq Facility Maintenance and Renovations Policy	Required	
7			Credit Waste performance	8	
0			Credit Purchasing	1	
19	0	0	Indoor Environmental Quality	22	
Y			Prereq Minimum Indoor Air Quality Performance	Required	
Y			Prereq Environmental Tobacco Smoke Control	Required	
Y			Prereq Green Cleaning Policy	Required	
19			Prereq Indoor Environment Quality Performance	20	
0			Credit Green Cleaning	1	
0			Credit Integrated Pest Management	1	
0	0	0	Innovation	1	
0			Credit Innovation	1	
73	0	0	TOTALS	Possible Points: 100	
Certified: 40-49 points, Silver: 50-59 points, Gold: 60-79 points, Platinum: 80+ points					

Figure 34: The entire project's certification eligibility, source: Author based on LEED v4.1 Existing Building O+M guidance.

On the Arcskoru website, after inputting the last 12 months' water bills, the building's water efficiency rating was 11 out of 15 credit points. Implementing scenarios 2 and 3 by applying PV panels and replacing LED lighting could achieve 30 points out of 35 in the Energy and Atmosphere category and 7 out of 9 points for waste diversion in the material and resource categories. Because of the building's good air quality, cleanliness, natural light, and thermal comfort, the Tabriz building received 19 out of 22 credit points for indoor environment quality.

In the questionnaire, most residents indicated they were delighted. Furthermore, the building lacked points for site management, grid Harmonization, purchasing, green cleaning, and integrated pest management. In addition, due to the lack of an accredited LEED professional, it scored 0 credit points for innovation. With 73 points out of 100, it was determined that the Tabriz case study has an excellent chance of being gold LEED certified, as indicated in Figure 34, LEED v4.1 for Operations & Maintenance: Existing Buildings.

CHAPTER VII

CONCLUSION

This study provides sustainable retrofitting solutions for a five-story reinforced concrete residential building considering the LEED v4.1 Operations and Maintenance and compares the resource consumption and carbon emission release between the retrofitted building and conventional building. The results highlight how well LEED standards can be applied to improve existing residential buildings' operational efficiency and environmental performance. Effectively incorporating sustainable retrofits reduces the adverse effects on the environment, enhances occupant comfort, and reduces energy consumption. Although the study demonstrated the benefits of implementing LEED v4.1 O+M criteria, it is critical to recognize the inherent complexity and possible difficulties associated with retrofitting older buildings. The results of this research will contribute to (1) the AEC industry and literature by indicating the design process and value of sustainable retrofits for residential buildings based on LEED v4.1 Operations and Maintenance. (2) Practitioners in sustainable construction projects and researchers focusing on green buildings could benefit from the results of this research, and (3) to improve the environmental efficiency and overall sustainability of residential buildings while complying to the most recent LEED requirements.

Based on the LEED v4.1 O+M, nine alternative scenarios were used in the study to reduce the building's current energy consumption and CO₂ emissions. These scenarios include installing PV panels, exterior wall insulation, and double-glazed windows instead of single-glazed ones. Additionally, apply a light hue to the roof, switch the orientation of the exterior lights, and replace lighting fixtures with LEDs.

Therefore, the first scenario's study, which corresponds to the current building before the retrofitting, indicates an annual energy use of 101.3 MWh. After installing PV panels in scenario 2, the yearly energy usage dropped to 82.84 MWh. In scenario 3, LED lighting was replaced with CFL lighting, total EUC equals 98.83 MWh. Moreover, the total energy used dropped to 82.11 by installing a 100 mm thick thermal EPS insulating layer on the building's exterior wall. Additionally, double-glazed windows were installed instead of single-glazed ones to reduce the energy used for heating, resulting in an annual reduction of 95.87 MWh. The analysis's result of scenario 6 reveals that altering the roof material and color was useless since the total EUC of this scenario increased to 101.42 MWh, while scenarios 7 and 8, which were about waste performance and external lighting direction, were successfully carried out. The final scenario, which combines the previous scenarios and applies all of them simultaneously to the building, has a result of 56.98 MWh, about 43% less energy consumption than building annual energy use. Additionally, the combined scenario reduces the annual CO₂ emission in the existing building from 34437.89 kg to 16668.9 kg. This represents a 51% decrease in CO₂ emissions. According to the case study findings, the Tabriz case study has an excellent chance of receiving LEED Gold certification by scoring 73 points out of 100 in LEED v4.1 for Operation and Maintenance in existing buildings. The results reveal that each method has a varied effect on lowering energy consumption and CO₂ emissions in existing buildings. The findings of this study show that combining numerous retrofit methods can save up to 50% of energy in Tabriz-climate residential buildings.

The research has some limitations. One of research limitations is that LEED standards are primarily created for North American environments presents a problem, given Iran's particular cultural and contextual variances. Furthermore, the scarcity of critical LEED-recommended sustainable materials and technology in the Iranian

market raises worries about their broad adoption. Moreover, the difficulty of acquiring required data for specific LEED credits is exacerbated by a need for defined metrics and available information in Iran, potentially affecting the precision of sustainability performance evaluations. Furthermore, choosing Iran as the country in the LEED system makes it currently impossible to register or certify the project due to geopolitical limitations and the limited local availability of sustainable technologies, avoiding seamless adherence to standardized green building practices. These limitations emphasize the need for further study to customize sustainable techniques to the specific conditions and resources in the case study's location construction context.

Future studies could examine the long-term cost of the assessed scenarios, considering aspects like maintenance costs and return on investment. Also, LEED v5, the latest version of the LEED green building certification, can be used in future studies. The building sector can play a critical role in improving the global goal set by the Paris Climate Agreement and promoting progress toward a more sustainable and environmentally friendly built environment by utilizing the complete LEED v5 framework.

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PUBLICATIONS

- Hajizadeh, S. Seyis, S. Ashrafiyan, T. (2022) "Sustainable Retrofit Solutions for Decreasing Energy Consumption and CO₂ emission of a Residential Building in Tabriz, Iran." Building Simulation and Optimisation.

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